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ROYAL SOCIETY.

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REPORTS OF THE GRAIN PESTS (WAR) COMMITTEE.

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CONTENTS.

1. Introductory Note. By the Chairman of the Committee.

2. Report on the Effect of Air-tight Storage upon Grain Insects.
Part I. By Prof. A. Dendy, F.R.S.

26.4.19

INTRODUCTORY NOTE ON THE WORK OF THE GRAIN PESTS (WAR) COMMITTEE.

DRAWN UP BY THE CHAIRMAN OF THE COMMITTEE.

The Grain Pests Committee was appointed by the Council of the Royal Society in June, 1916, as the result of a correspondence with the Board of Agriculture and Fisheries, in which the Board requested the Royal Society to appoint a Committee "in relation to the damage done to grain by insects." The Committee included a representative of the Board of Agriculture (Mr. J. C. F. Fryer), and a member appointed by the milling trade (Mr. Oswald E. Robinson). The Council's reference to the Committee was "to consider the relative economic importance of the species and varieties of insects infesting grain, to suggest measures for combating them, and to enquire into the extent of the actual loss from these pests," and they placed a sum of £200 at the disposal of the Committee for preliminary expenses. Other grants have been voted since as required.

The Committee at once got into relation with the appropriate Government Departments or Committees in India and the overseas Dominions, and steps were taken for the establishment of corresponding committees in Canada, Australia, South Africa, New Zealand and Russia.

It was decided that the work should be divided between London (dealing with the Insecta) and Liverpool (with the Acarida). The London work was in the first instance carried on at two centres: (1) At the British Museum (Natural History), under the direction of Mr. J. H. Durrant; (2) At the King's College Department of Household and Social Science, under the direction of Prof. Dendy and Dr. Gertrude Dixon. Since then sections of the London work have been transferred to the Zoological Department of King's College (Prof. Dendy), the Physiology Department of the Bedford College for Women (Dr. Edkins) and the Zoological Department of the University of Oxford (Mr. E. S. Goodrich).

At Liverpool the work, under the direction of Prof. Newstead, was at first carried on in the laboratories of the School of Tropical Medicine, but it was later transferred to the Department of Zoology in the University.

Representatives of the Liverpool Grain Trade (Mr. Edward Paul) and of the Incorporated National Association of British and Irish Millers (Mr. A. E. Humphries) were added to the Committee, and relations with the trades concerned were established both in London and Liverpool so that facilities might be obtained at the warehouses and mills, and that samples might be secured for laboratory investigation. The Local Government Board appointed Dr. MacFadden as a representative on the Committee. The other members were the scientific investigators appointed by the Royal Society.

The sub-division of the work eventually decided upon was as follows:—

At the British Museum, Mr. Durrant, with some assistance, undertook the faunistic and statistical investigation of samples of grain, with a view of identifying the insect pests, in order to compile a complete list, with statistics as to the relative numbers of the different species and the proportion of injured and uninjured grains in a sample, their respective weights, and the amount of damage done by the various insects.

At King's College, Prof. Dendy, with assistants, undertook the investigation of the life-histories and bionomics of weevils and other imported insects. The Chalcid Hymenoptera, parasitic upon the weevils, were dealt with at Oxford, by Mr. Goodrich.

At the Bedford College, Dr. Edkins experimented on the life conditions of the flour moth, *Ephestia kuhniella*, and the possibility of controlling this and other grain and flour pests by fumigation with various gases, including ozonized air.

At the Liverpool Laboratory, Prof. Newstead, with the assistance of Miss H. M. Duvall, undertook the investigation of mites (Acarida) as grain and flour pests from all points of view—faunistic, bionomic and experimental.

The work at the King's College Department of Household and Social Science consisted of the statistical investigation of samples with a view of determining the amount of damage caused by the pests in question. This work has now ceased.

After the first six months of work it was decided that the statistical enquiry had established the fact that a very considerable amount of damage to grain was sustained by the action of the pests, and that the Committee was justified in recommending further investigation on faunistic, bionomic, developmental and experimental lines at the various laboratories concerned, in the hope of being able to arrive at recommendations in regard to preventive or remedial measures.

Interim reports have been received from time to time from Mr. Durrant on his faunistic work, from Prof. Dendy and Mr. Goodrich on the bionomics of weevils, from Dr. Edkins on his experiments with the flour moth and from Prof. Newstead and Miss Duvall on their investigation of acarids in grain and flour; and memoranda have been prepared and issued dealing with (1) the protective treatment of stored grain by the application of heat and other methods, and (2) the investigation of acarids in relation to grain and flour.

During the eighteen months since the appointment of the Committee, in addition to making reports on samples of infested grain and flour submitted for examination and report by Government Departments and by the grain and milling trades, correspondence has been carried on with the Government Departments or special committees in Australia, Canada, the United States, Italy, Malta and Cyprus, and answers have been given to enquiries from the Royal Commission on Wheat Supplies, the Imperial Institute, and some members of the trades concerned.

The results obtained by the Committee's investigations are being published in two series:—

(1) "Memoranda," similar to those of some other Royal Society War Committees, containing brief statements, possibly only of a provisional nature, but which it is thought should be made known without delay to those concerned. Of these, the three following have been issued (January 24, 1918):—

Memorandum No. 1.—On current views as to the damage done to stored grain and flour by insects and mites, and the best means of prevention.

Memorandum No. 2.—On Acarids (mites) occurring in stored grain and flour.

Memorandum No. 3.—Report to the War Committee of the Royal Society on the work of the Grain Pests (War) Committee.

(2) "Reports," in octavo form, of a more detailed and permanent nature, containing full accounts of the investigations, both scientific and economic. The present publication, giving the results of certain of Prof. Dendy's experiments with weevils, is the first of these Reports; a second, containing Prof. Newstead's investigations on the Acarid pests is nearly ready and will, it is hoped, be issued during the summer.

W. A. HERDMAN.

MAY, 1918.

REPORT ON THE EFFECT OF AIR-TIGHT STORAGE UPON GRAIN INSECTS.—PART I.

By ARTHUR DENDY, D.Sc., F.R.S.
Professor of Zoology in the University of London.

During recent years the opinion appears to have been widely accepted amongst those who have concerned themselves with the subject that grain weevils are almost independent of ventilation and can live and thrive indefinitely in tightly closed vessels. This belief received a considerable amount of justification from a paper published in 1906 by Professor F. J. Cole, "On the Bionomics of Grain Weevils," in which are given some results of an investigation originally undertaken at the instance of a firm of underwriters. The author treats the subject entirely *de novo*, making no reference to previous writers. The following quotations are particularly significant from our present point of view.

"A non-ventilated atmosphere at about 80° F., charged with water vapour (no matter how poor in oxygen, and contaminated with carbonic acid gas), provides the most favourable conditions for the life and reproduction of these weevils" (p. 5).

"Hence also almost any accumulation of CO_2 in the atmosphere in which the weevils are living may be disregarded as a preventive agent" (p. 7).

"In the face of these and my other results it would be absurd to hold either that weevils require a free play of air, or even that free access to air, when possible, is favourable to their existence" (p. 8).

"It is therefore important that the ravages of the insect should be confined to within as narrow limits as possible. This is done by stowing the grain in sacks, and by thorough ventilation of the cargo. These precautions of course result in keeping down the temperature and in carrying off water vapour, and are certainly the best that could be followed" (p. 8).

We may fully admit the importance of warmth and moisture in promoting the development of the weevil, but in view of the native Indian and Maltese experience, to be quoted presently, and of my own experimental results, the practical recommendation embodied in the last quotation would certainly seem to require reconsideration, at any rate from the point of view of damage by weevils, whatever may be its value for other reasons.

Other writers have investigated the problem since Professor Cole's paper was published, but it must be admitted that very little practical advance has been made, while the question of air-tight storage seems to have received very little attention. Professor Maxwell Lefroy, it is true, did some experimental work with wheat and weevils in closed bottles, but this appears to have been done entirely from the point of view of the moisture-content of the wheat and its effect upon the weevils. He finds that wheat containing from 9 per cent. to 16 per cent. of moisture "breeds weevil," and although the bottles were kept closed for six weeks the weevils still continued to thrive in many of them. From 8 per cent. of moisture downwards he found the wheat to be immune to weevils. His results, however, are not altogether consistent. Thus he says: "The 12 per cent wheat, under the same conditions, did nothing at all, nor has any weevil developed since. In the 14 per cent wheat there has been the same result as in the 10 per cent in one bottle only, not in all; and in that bottle not as much breeding as in one of the 10 per cent bottles. The 16 per cent wheat is exactly the same as the 14 per cent. . . . The behaviour of the 12 per cent lot is inexplicable. . . . It must be put down to experimental error" (1909, p. 106). It is suggested that the wheat may give off carbon dioxide but apparently it was not considered necessary to secure that the bottles were really hermetically sealed and one is led to suspect that the discrepancy in results is due to the fact that some had tight-fitting stoppers and others not. My own work indicates very clearly that the effects of hermetical sealing upon the weevils are such that no experiments with closed bottles can be regarded as of any value unless this factor is taken into account.

Precisely the same criticism applies to an elaborate series of experiments on the influence of the moisture content of the wheat published by Messrs. Barnes & Grove in 1916. These experiments were made upon three different grain beetles, *Attagenus undulatus* (= *Trogoderma khapra*), *Rhizopertha dominica* and *Calandra oryzæ*. I will confine my comments to the results obtained with the last-named, which is the only one of the three with which I have myself as yet completed experiments from this point of view. Messrs. Barnes & Grove record the results of thirty experiments with this beetle in wheat of various degrees of moisture. Fifteen of these experiments were made in glass-stoppered bottles and fifteen in corked tubes sealed with paraffin wax. The percentages of moisture ranged from five to fifteen. The vessels were kept closed for two or three months, and when the contents were examined only two of them were found to contain any live weevils at all, and both of these were stoppered bottles. In every one of the sealed tubes all the beetles were dead. There is no proof here that the moisture content of the wheat had anything to do with the result, which, on the other hand, entirely supports my views as to the effect of hermetical sealing.

Several writers have also experimented directly with carbon dioxide as an insecticide for grain pests. Cole (1906), as we have already seen, attributed very little importance to this reagent. Indeed, he claims to have kept weevils alive for several days in a moist atmosphere containing 80 per cent. of carbon dioxide, although he admits that pure dried carbon dioxide is very fatal.

Mr. F. Noël-Paton (1913) suggests the use of carbon dioxide on a large scale for elevators, bins or pits, and remarks that the receptacle must be air-tight. He goes into the question of the cost of plant for producing and purifying the gas in India and gives an estimate of £1,333 for a plant capable of producing half a ton of gas per diem, at a cost of a penny per pound. His own experiments lead him to the conclusion that " only when wheat is fairly dry does carbon dioxide kill weevils quickly."

Barnes and Grove (1916) deal with the question of carbon dioxide in great detail, and record the results of numerous experiments. They confirm the views of previous writers as to its lethal effect upon the weevils but they treat the question chiefly from the point of view of its influence upon the germinating power of the wheat. They say, however, that in one case " even in an atmosphere containing 50 per cent. of carbon dioxide the weevils had extended their ravages to fresh grain before succumbing to the effects of the gas " (*l.c.*, p. 223), but the evidence on which this statement rests appears to be very unsatisfactory. They record two experiments with wheat in closed bottles to which no carbon dioxide had been added and find that in the course of about two months about 17·5 per cent. of carbon dioxide had been produced from (apparently) 40 grammes of wheat, 53·7 per cent. of which was already damaged by weevils. I cannot make out from their tables how many weevils were actually present, and their results are given in a form which it is by no means easy to follow from our present point of view. Their general conclusion is that " no inert gas (such as carbon-dioxide) can be economically used as an asphyxiating agent for these insects, owing to their ability to enter on a ' hibernating ' stage when atmospheric oxygen fails them, and also because carbon-dioxide itself materially affects the germinating power of wheat " (*l.c.*, p. 260). These objections, however, seem of little practical importance in the case of grain which is being stored for long periods and is intended for use merely as food.

It is curious how little attention has been paid by scientific experimenters to the methods of grain-storage actually in use in various parts of the world. Had these been thoroughly investigated it is probable that very different results would have been arrived at.

As the Indian native method of wheat storage is of great practical importance and forms the starting point of my own experiments, it seems desirable to quote the information on the subject collected by

Mr. E. C. Cotes thirty years ago and recorded in his valuable memoir on the Wheat and Rice Weevils in India (1888). The salient quotations are as follows:

"Wheat stored, so as to be practically airtight, is said to be free from the attack of weevils. The method, which seems to have been widely adopted in India, is as follows: holes are dug in the ground, or round buildings of mud are erected, the floor and walls in each case being lined with chaff or sand, and the grain covered with a layer of the same material, the whole being covered in with closely packed earth. Wheat so stored for three years has been found, on opening, to be quite sound" (p. 5).

"Ventilation causes the grain to be more infested by weevils, as wheat, packed in bags, gets more weevilled than wheat stacked in bulk or pile which is more air-tight" (p. 24).

"Ventilation and stirring the grain about appear to develop the pest" (p. 26).

"Natives do not care and do not bother their heads about weevils, knowing that in their air-tight pits underground, nothing will attack the grain" (p. 26).

"The only method to prevent destruction of grain from the weevil is to make the granary air-tight" (p. 27).

"We have personally seen pits opened after three years and the wheat to be in as fresh and sound a condition as ever" (p. 28).

It is important to notice that these statements convey the opinions of practical men, being taken from reports collected by Messrs. Ralli Bros., of Calcutta, from their different agencies, and there appears to be no difference of opinion amongst the natives with regard to the effect of storage in air-tight pits.

Mr. F. Noël-Paton, Director-General of Commercial Intelligence in India, writing in 1913, takes, it is true, a less optimistic view with regard to this method of storage. He says (1913): "Quantities of wheat are still stored in pits. These are lined with straw and chaff and sometimes, it is said, with a plaster compounded of mud and cowdung. The wheat is placed in them in bulk and is covered with straw, earth and thatch. Protracted storage in such pits results in damage more or less serious. This damage appears in the form of moulds and results in discolouration and bad smell. But there is evidence that the ravages of weevil are to some extent inhibited by the conditions set up. This is believed to be due to the generation of carbonic acid gas in the processes of decomposition. It is well understood that it is dangerous to enter such pits when they are first opened; and there is on record at least one authenticated case of a dealer being convicted of a rash and negligent act which occasioned the death of several labourers sent into a pit prematurely" (pp. 2, 3).

There is, at least, no evidence here that can be taken as seriously controverting that collected by Messrs. Ralli Bros., and the damage referred to very possibly resulted from carelessness and may be easily preventable. Moreover, as we shall see presently, the evolution of carbon dioxide is by no means entirely dependent upon processes of putrefaction, though it may probably be greatly increased thereby.

Information which has lately been obtained by Professor R. Newstead, F.R.S., from Professor Zammitt, C.M.G., with regard to the construction of granaries in Malta is even more convincing than the native Indian evidence as to the advantages of air-tight storage. It is sufficient here to mention the following facts. The granaries in question have the form of deep pits made in the ground. The wall of the pit is composed of rock or masonry and the interior is lined with dry straw. "The air within the granary becomes very heavily charged with carbon dioxide, as a result of the ordinary process of respiration by the grain, and before removing the grain the granary must be thoroughly ventilated by an air-pump or fan. The carbon dioxide acts very effectively as an insecticide, so that in a properly constructed granary, watertight and airtight, no insect can develop."

This evidence appears to me to be quite conclusive as to the value and practicability of air-tight storage on a large scale. I was not aware of it until after the first draft of this report had been presented to the Royal Society's Committee. It supports in the most striking manner the conclusions which I had arrived at from my own experiments and, indeed, at first sight, almost seems to make these experiments superfluous. The matter is so important, however, from the practical point of view, that it seems desirable to bring forward perfectly definite experimental evidence with regard to the effect of hermetical sealing upon weevils, evidence which, so far as I am aware, has never yet been supplied, and this especially in view of the publication of the widely quoted paper by Professor Cole referred to above, which must certainly tend to discourage the practice of air-tight storage.

It is remarkable how a practice, based upon a definite scientific principle, has sometimes been in existence for centuries amongst people who have no knowledge whatever of the principle involved. The scientific authorities in Malta are, of course, no longer guided merely by rule of thumb in their method of grain storage, but the Indian native farmers probably have no scientific knowledge whatever, and construct their granaries in a particular way simply because their forefathers did the same. Even more remarkable from this point of view is the practice of the Natal farmers with regard to the storage of maize. They use large tanks of corrugated iron. These are filled almost full and candles are then placed in the tanks and allowed to burn until the air is exhausted, after which the tanks are securely closed. Some farmers go so far as to state that the burning candle kills all weevils already in the grain and prevents others from entering.* Here again either increased carbon dioxide or diminished oxygen pressure (if not both) would appear to be the agent at work in securing the desired result.

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* This information is taken from a work on "Maize," by Burtt Davy (Longmans Green, 1914), where it is quoted from C. B. Simpson, Entomologist to the Transvaal Department of Agriculture.

We may now pass on to the consideration of my own experiments. I shall confine myself in this Report to the two grain weevils, *Calandra granaria* and *Calandra oryzæ*. The experiments are, however, in process of extension to other grain insects, notably *Rhizopertha dominica* and *Trogoderma khapra*, of which I have been breeding stocks for the purpose, and I am already in a position to state that hermetical sealing (at 31° C.) appears to be quite as effective in the case of Rhizopertha as in that of Calandra.

Owing to the low temperature of our winter months, most of the experiments were conducted in incubators. In all of these the atmosphere was kept thoroughly moist by means of a vessel of water or a wet sponge, so as to secure favourable conditions for the weevils in the control jars and breeding jars. The weevils were kept in glass vessels in which their behaviour was observed at frequent intervals through the glass. Great care should be taken to seal the air-tight vessels effectively, and it was found in practice that a very slight leak is quite sufficient to enable the weevils to go on living indefinitely. Where glass cylinders are employed these should be sealed by means of glass discs luted on with vaseline and further secured with melted paraffin wax. If glass-stoppered bottles are used the stopper should be put in with vaseline and a coating of paraffin wax thickly painted round the junction of stopper and neck. Narrow-necked glass flasks, fitted with inlet and outlet tubes, had to be employed in cases where it was desired to make an analysis of the gas contents at the close of the experiment. It was found that in these cases ordinary corks were very liable to leakage even when carefully waxed, and they should be thoroughly tested after sealing by submerging in warm water and looking for air-bubbles.

In the sealed jars the weevils tend to collect either above the wheat or between the wheat and the side of the jar, and it is very interesting to note how they gradually became torpid and finally rigid, sometimes in the most life-like attitudes.

Of course, it is impossible to ascertain when the weevils are actually dead without opening the jar and giving them a chance to revive under favourable conditions, but from the practical point of view it matters little whether they are dead or dormant, so long as they are kept sealed up. Moreover, there seems to be little justification for the idea that they can pass into a lengthy hibernation under these conditions without perishing. My experiments indicate that torpidity passes into death within a few days, at any rate in the case of the adults.

The samples with which the experiments were made were supplied to me as clean wheat by various firms. Some of them proved to be not entirely free from insect pests (Calandra or Rhizopertha), and this fact is probably the chief reason why some of the experiments showed a slight apparent increase in the number of weevils (dead) when the hermetically sealed jars were opened. Another reason may be that the original counts of live weevils put in were not quite accurate, for in dealing with large numbers of very active insects it is quite easy to make a mistake. Such discrepancies, however, in no way affect the results, and it is impossible that the weevils could really have increased in number in so short a time as that involved in these particular cases.

A much more serious effect of using contaminated wheat arises in connection with the determination of the amount of carbon dioxide produced and the amount of oxygen consumed in the sealed flasks. If an unknown number of weevil larvæ are present concealed in the grains no conclusions can be drawn from the results of analysis of the gases present as to the relative parts played by the wheat and the weevils respectively in producing the lethal effect. Several of my experiments have been vitiated in this way, and it is obvious that the utmost care must be used in securing perfectly clean grain for such experiments.

Experiment A.

The effect of sealing a sample of wheat infected with Calandra granaria *at 20° to 22° C. for forty days.*

This experiment was commenced on November 10, 1917.

Two small, wide-mouthed glass jars of equal size, &c., were filled with weevily wheat (about 91 grammes each) from an Australian sample infected with *Calandra granaria*. Twenty-five additional *Calandra granaria* were added to each jar to make sure of the presence of plenty of live weevils. One jar was hermetically sealed with a glass stopper and paraffin wax, the other was closed only by muslin tied over the mouth and was kept as a control.

The temperature of the incubator in which these jars were placed ranged from 20° to 22° C. until December 18, when the gas supply was turned off owing to an air-raid. There was some difficulty in regulating it again and on December 19 it accidentally went up to 50·5° C. for a few hours. The jars were then transferred to another incubator. On December 20 the contents of the two jars were turned out and examined.

The sealed jar was found to contain fifty-eight dead weevils only, none of which could be revived by placing under favourable conditions. The control jar contained twenty-four dead weevils and sixty-three living ones.

Experiment B.

The effect of sealing a sample of wheat infected with Calandra granaria *at about 25° C. for eight days.*

The grain used was from the same sample as in Experiment A, badly infected with *Calandra granaria* and *Silvanus surinamensis*. This sample had now been standing in the laboratory, at room temperature, since October 20, and the weevils had become almost quiescent in the cold. On January 7, 1918, two glass cylinders were nearly filled with the wheat, which had been selected from those parts of the bulk sample which contained most weevils and thoroughly mixed in a basin. The two cylinders, both covered only with cambric, were placed in an incubator at 25° C. During the course of the experiment the temperature was never much higher than this, but there was some trouble with the regulation and it ranged downwards to about 19°, dropping once for a short time to room temperature.

After eight days, on January 15, live, active weevils were observed in both cylinders, and there was apparently nothing to choose between the two. One was then hermetically sealed, the other remaining as before. On January 16 active weevils were observed in the unsealed cylinder but none in the sealed one.

On January 23, eight days after sealing, the contents of both cylinders were turned out, the ventilated cylinder contained many active weevils, but no live insects were seen in the sealed one. On January 25 the contents of the sealed cylinder were more carefully examined, but no live insects were found, it having in the meantime been resealed. Both cylinders were replaced in the incubator on this date covered with cambric only.

On February 11 and 12 the contents of both cylinders were again turned out and examined.

The originally unsealed cylinder was found to contain 296 live Calandra, 148 dead Calandra, 9 live Silvanus, 29 dead Silvanus, and fragments of beetles. The cylinder that had been sealed contained 34 live Calandra, 221 dead Calandra, 1 live Silvanus and 11 dead Silvanus. All the dead insects were tested by incubation and there were no revivals.

From this experiment it is evident that a very badly weevilled sample of wheat is greatly benefited by hermetical sealing, be it even for so short a period as eight days at a quite moderate temperature. Had the sealing been maintained for a few days longer there can be no reasonable doubt that the wheat would have been completely sterilized as regards insect life. As it was it is probable that some of the larval stages survived the treatment.

EXPERIMENT C.

The effect of sealing wheat containing a mixture of Calandra granaria *and* C. oryzæ *at* 31·5° *C.*

This experiment was commenced on December 12, 1917. Two glass jars were employed, each having a total capacity of about 450 c.c. These were filled each about three-quarters full of wheat that had been sent to me as a clean sample (No. 2 Club Calcutta). Each was infected with 100 *Calandra granaria* and 100 *C. oryzæ* and covered with cambric tied tightly over the wide mouth. The two jars were then placed in an incubator kept at a temperature of about 31·5° C.

On December 28 many active weevils were observed in both jars. One of the jars was now hermetically sealed by means of a glass stopper and paraffin wax; the other was left unsealed as a control. It may safely be assumed that the atmosphere in both jars was pretty thoroughly saturated, and that the grain contained a high percentage of moisture, after being in the incubator for 16 days.

Already on December 29, in less than 24 hours from the time of sealing up, all activity had ceased in the sealed jar, so far as could be ascertained by examination through the glass, though many weevils were visible, and no sign of activity was again manifested, although the jar was examined repeatedly during the course of the experiment.

On January 10 the sealed jar was opened and its contents examined, 199 dead weevils being found and no live ones. The dead weevils were incubated in a moist atmosphere overnight but none revived. The wheat in the jar was found to weigh 298 grammes.

On January 11 the unsealed control jar was turned out and found to contain 84 dead weevils and 205 live ones, and there were probably a good many more enclosed in wheat grains.

The live insects (only) were replaced in the jar, which was put back, covered with cambric, in the same incubator. By April 6 the number of live adult weevils had increased to 3,634, but of these only 221 were *C. granaria*, all the remainder being *C. oryzæ.*

EXPERIMENT D.

The effect of sealing wheat containing Calandra oryzæ *in a moist atmosphere at* 31·5° *C.*

This experiment was commenced on December 12, 1917, and was similar to C, except that the wheat was weighed at the beginning of the experiment and was infected with only 100 weevils all of the same species (*Calandra oryzæ*), while precautions were taken to ensure the continued moisture of the atmosphere in the sealed vessel. Two similar glass cylinders were used, having a capacity of about 295 c.c., and in each were placed 150 grammes of wheat (No. 2 Club Calcutta) and 100 weevils. The air space left above the wheat was about one-third of the total space in the cylinder. Each was covered with cambric and placed in an incubator kept at a temperature of about 31·5° C.

On December 27 live weevils were observed in both cylinders. One of the cylinders was supplied with a 4-inch test-tube of water, covered with muslin and plunged in the wheat (considerably reducing the air space), and then sealed in the usual way. The other was left as a control. (A smear of vaseline made inside the control on the following day showed that vaseline has no poisonous effect upon the weevils.)

On December 28 several weevils were observed on top of the grain in the sealed jar and two on the cover of the test-tube in very life-like attitudes, but none showed any activity and no signs of life were observed throughout the further course of the experiment. The two on the cover of the test-tube remained there in the same position all the time.

On January 15 the contents of the two cylinders were turned out and examined. The sealed one was found to contain 100 dead weevils* and no live ones. The control contained 19 dead weevils and 344 live ones loose amongst the grain, besides numerous uncounted weevils in the interior of grains.

The weevils from the sealed jar were placed in the incubator under favourable conditions but none revived.

It will be observed that the whole period of this experiment was only 34 days, during which time the weevils in the control cylinder increased to at least three and a half times their original number. Now the period of a complete life-cycle of *Calandra oryzæ* in India ranges, according to Messrs. Barnes and Grove, from 21 to 124 days, according to the time of year. I have not yet determined the period in my incubators but it is pretty safe to assume that it is not less than 21 days. There was an interval of only 19 days between the sealing of the one cylinder and the examination of the contents of both. Therefore it is almost certain that eggs were deposited before the sealing up took place. There had been 15 days during which this might have been done and during which larval development might have been going on. We are justified in assuming, then, that at the time of sealing the cylinder must have contained not only the original 100 adults but also eggs and larvæ in various stages of development, from which we may conclude, with a considerable degree of confidence, that hermetical sealing destroys the eggs and larvæ as well as the adult insects.

The weevils and grain from the control jar were all replaced and put back in the incubator, and by February 15 the number of live adult weevils found amongst the grain had increased to 1,776 and there were doubtless more buried in the grains (a little fresh wheat had been added).

EXPERIMENT E.

The effect of sealing wheat containing Calandra oryzæ *in a dry atmosphere at* 31·5° *C.*

This experiment was commenced at the same time as D and was exactly the same except that a test-tube of calcium chloride was plunged in the wheat in the sealed cylinder instead of a test-tūbe of water. Live weevils were observed before sealing up, but on the next day no sign of life could be detected and no movement was observed throughout the remainder of the experiment.

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* And one dead Rhizopertha.

On January 15 the contents of the cylinder were turned out and 100 dead weevils and no live ones were found. The weevils were placed in the incubator with a view to possible revival but with no result.

EXPERIMENT F.

The effect of sealing wheat containing Calandra oryzæ *at about* 21·5° *C.*

This experiment, in its first stage, lasted from January 14 to January 18, during which time the temperature of the incubator, taken once a day, ranged from 21·2° to 21·6° C. (neglecting any slight temporary fall due to opening the door).

Two glass cylinders were employed, each with 150 grammes of No. 2 Red Winter wheat and 100 *Calandra oryzæ.* The wheat nearly filled the cylinders.

One cylinder was sealed up in the usual way. This was done before the cylinder was placed in the incubator at all, so that the wheat was ordinarily air-dry and the atmosphere that of the laboratory. The other cylinder was covered with cambric and used as a control.

Both cylinders were placed in the incubator at about 4 o'clock on January 14. On the 15th, at 10.15 a.m., the weevils appeared to be normally active in both cylinders. On the 16th there was again considerable activity observable in both. On the 17th only very feeble movements could be seen in the sealed cylinder, and on the 18th, at 10 a.m., all movement had ceased, while, of course, normal activity continued in the control.

It appears, then, that even at the lower temperature hermetical sealing caused the complete suspension of activity on the part of the weevils in less than four days. This cylinder is being kept for demonstration purposes and has therefore not been opened up in order to determine whether the weevils are actually dead, but, in view of other experiments, it is hardly necessary to do this.

On April 9 the contents of the control cylinder were turned out and very carefully examined, 975 live adult weevils were counted and 284 dead ones.

EXPERIMENT G.

The effect of sealing wheat containing Calandra oryzæ *at* 21·5° *C. in a moist atmosphere.*

This experiment was commenced at the same time as F, and was carried out in exactly the same way, except that a small test-tube of water, covered with muslin, was plunged in the wheat in order to moisten the atmosphere. The result was exactly the same, except that all movements of the weevils appeared to be already completely suspended by 10.40 a.m. on January 17. Several of the weevils climbed up onto the muslin cover of the test tube and became rigid there in very life-like attitudes. This cylinder is also being kept for demonstration purposes, so that no attempt was made to revive the weevils.

EXPERIMENT H.

The effect of sealing wheat containing Calandra oryzæ *at room temperature* (*about* 9·5° *to* 13° *C.*).

The object of this experiment was to test the effect of hermetical sealing at a still lower temperature. The cylinders were therefore kept in the laboratory, at a temperature ranging from about 9·5° C. to about 13° C. (during the daytime), instead of being placed in an incubator.

On January 24 two similar glass cylinders were nearly filled with No. 2 Red Winter wheat and 100 *Calandra oryzæ* were placed in each. One was sealed as usual and the other covered with cambric. Movement of the weevils in the sealed cylinder continued up to February 2, when it had become extremely feeble. They were not examined on the 3rd, which was a Sunday, but on the 4th no movement could be detected on careful examination with a lens. On February 5 the sealed cylinder was opened (after having been sealed for 12 days) and covered with cambric, without disturbing the weevils, and both cylinders were placed in an incubator at about 31° C., to give every chance of recovery. On February 6 the weevils in the cylinder that had not been sealed exhibited normal activity while there was no sign of recovery in those in the cylinder which had been sealed. On February 8 the contents of the two cylinders were turned out and examined. The one which had not been sealed contained 95 live weevils and five dead ones; in the one which had been sealed the count gave 99 dead weevils and no living ones.

This experiment shows clearly that hermetical sealing is effective, under the conditions of the experiment, at ordinary room temperature, the weevils being killed in 12 days.

The capacity of the sealed cylinder was 273 c.c., the weight of wheat in it 188·5 grammes, and the air space above the wheat about one-seventh of the total volume of wheat and air.

EXPERIMENT K.

The effect of sealing wheat containing Calandra granaria *at* 31·5° *C.*

This experiment was commenced on December 31, 1917, in the afternoon, and differs from D and E in the following respects: (1) A different sample of wheat was used (Australian); (2) Sixty specimens of *Calandra granaria* were placed in each cylinder instead of 100 *Calandra oryzæ*; (3) The capacity of the cylinders were only about 160 c.c.; (4) No water or calcium chloride was placed inside the sealed cylinder; (5) The sealing up was done on the first day of the experiment, the cylinder being merely allowed sufficient time in the incubator to get warm, with a view to avoiding change of pressure inside. A control cylinder was treated in the same way except that it was covered with cambric instead of being sealed. The air-space above the wheat in the sealed cylinder was about one-quarter of the total capacity of the cylinder, that is, the cylinder was about three-quarters filled with wheat.

On the second day of the experiment (January 1) the weevils were active in both cylinders and there was no visible difference between the two. On the third day, however, the weevils appeared to be absolutely motionless in the sealed cylinder when examined at 10.30 a.m. and no sign of life was detected throughout the further course of the experiment, whilst activity continued in the control vessel. On January 18 the contents of both cylinders were turned out and examined. The sealed cylinder was found to contain 63* dead weevils, one dead Tribolium* and no live insects. The control contained only three apparently dead weevils and 62 live ones.

Experiment L.

The effect of sealing wheat containing Calandra granaria *at room temperature* (*about* 9·5° *to* 13° *C.*).

This was a companion experiment to H, but with *Calandra granaria* in place of *Calandra oryzæ*; it was conducted at laboratory temperature as before, but was commenced two days later. One hundred weevils were placed in each cylinder. The capacity of the sealed cylinder was 270 c.c., the weight of wheat 191 grammes, and the air space above the wheat about one-tenth of the total volume. Wheat from the same sample as in H was used.

The experiment was started on January 26. On February 1 movement of the weevils in the sealed cylinder was almost entirely suspended and on the 2nd no movement could be detected on careful examination with a lens. The weevils, as usual in sealed jars, had largely collected on top of the wheat, whereas, in the unsealed jar, they were well dispersed through the wheat and still showed some activity, though very lethargic on account of the low temperature (10° C.).

On February 4 and again on the 5th there was still no recognizable movement of the weevils in the sealed cylinder, and at about 1 p.m. on the latter date it was opened (after having been sealed for ten days) and covered with cambric and placed in an incubator at about 31° C., together with the cylinder which had not been sealed. About an hour later several weevils in the cylinder which had been sealed had already revived and were showing considerable movement. On February 8 the two cylinders were removed from the incubator and their contents turned out and examined. The one which had not been sealed was found to contain 86 living weevils and 14 dead ones, the one which had been sealed contained 37 living ones and 63 dead.

---

* None of these revived on incubation.

The treatment in this case had resulted in the death of a very large proportion of the weevils, 37 per cent., however, had evidently only been stupified and revived under favourable conditions. The sealing had not been continued long enough to kill them all. It will be remembered that in experiment H, where the sealing had been continued for two days longer, there were no revivals amongst the weevils (*Calandra oryzæ*). It is possible, however, that there may be some difference in the powers of resistance of the two species.

As it appeared to be important to obtain a numerical measure of the extent of the "weevilling" in these experiments an estimate was made of the number of grains of wheat per weevil, which proved to be about 52 in this case.

EXPERIMENT M.

Experiment with Calandra oryzæ *to demonstrate the part played by the wheat and the weevils respectively in bringing about the lethal effect.*

Nine similar glass cylinders were employed, ultimately sealed with glass discs in the usual way, except K, which was left unsealed as a control. Each cylinder was fitted with an inner glass tube, having an inside diameter of 9 mm. and covered at each end with cambric. This tube was fixed by means of gummed paper to the side of the cylinder and was used as a cage in which the weevils could be more easily observed than when scattered through the wheat, though still subject to the influence of any change in the composition of the atmosphere. In each cage 50 grains of live wheat were placed as food for the weevils. The remainder of the cylinder, outside the cage, was completely filled with wheat, either live or killed. The total air space determined in one of the cylinders (F) after the close of the experiment was found to be 75 c.c.

The cages contained 12, 24, 48 and 96 weevils respectively, and for each number a pair of cylinders was employed, one containing live wheat outside the cage and the other wheat from the same sample but killed by heating in a steam autoclave. A germination test gave 95 per cent. for the live wheat and *nil* for the killed. The moisture content of the live wheat at the commencement of the experiment was 11·93 per cent. and of the killed wheat 11·98 per cent. The wheat employed was No. 1 North Manitoba. The weevil was *Calandra oryzæ*.

The cylinders were lettered A to K and were fitted up as follows :—

A.	12	weevils in	cage ;	124·15	grammes	live	wheat outside	cage.
B.	12	,,	,,	112·25	,,	killed	,,	,,
C.	24	,,	,,	126·0	,,	live	,,	,,
D.	24	,,	,,	108·4	,,	killed	,,	,,
E.	48	,,	,,	122·9	,,	live	,,	,,
F.	48	,,	,,	114·8	,,	killed	,,	,,
G.	96	,,	,,	130·7	,,	live	,,	,,
H.	96	,,	,,	118·1	,,	killed	,,	,,
K.	96	,,	,,	(unsealed, no wheat outside cage).				

All the cylinders, with contents complete, were first covered with cambric and placed in an incubator at 31° C. on March 1 at 6 p.m. They were left to settle down till March 4, when they were sealed at about 3 p.m. (except K) and replaced in the incubator.

On March 5, at 11 a.m., the weevils were very active in all the cylinders.

On March 6, at 10.50 a.m., movement appeared to be completely suspended in G and H, while in all the others the weevils were still quite active. Another observation at 4.20 p.m. gave the same result.

On March 7, at 10.30 a.m., movement appeared to be entirely suspended in E, F, G and H, the weevils in A, B, C, D and K being still active. Another observation at 5.30 p.m. on the same day gave the same result except that one weevil in G showed very slight movement.

On March 8, at 10.50 a.m., the weevils in A, B, D and K were still active, but no movement could be detected in any of the other cylinders. Another observation at 3.45 p.m. gave the same result.

On March 9, at 10.30 a.m., the weevils in A, B and K alone remained active, indeed very active, and no movement could be detected in any of the others.

March 10 was a Sunday and the laboratory was not visited.

On March 11, at 12 noon, movement was completely suspended in A, but the weevils in B still showed a considerable amount of activity, while those in K, of course, were abundantly active. The weevils in B still showed considerable activity at 5 p.m. on the same day.

On March 12, at 11 a.m., movement was completely suspended in all the cylinders except K.

On March 13, at 11.30 a.m., there was again no movement except in K. The inner tubes were then removed from cylinders A to H and incubated overnight to test the revival capacity of the weevils. The only revivals were two from cylinder B, the last to go under. All the grain outside the tubes was examined for weevils and none were found, and no weevilled grains were seen. It is fairly safe to assume that the results of the experiment were not vitiated by the accidental presence of weevils (or larvæ) other than those put in.

The results of this experiment demonstrate, as before, the lethal effect of hermetical sealing upon the weevils. They also indicate that this effect is directly proportional to the number of weevils present (or that the time taken to kill the weevils is inversely proportional to that number), and, therefore, to the rate at which carbon dioxide is produced and oxygen consumed, although the proportion is evidently not a simple one. The results obtained with the 24 and 12 weevils respectively further indicate that the live wheat contributes something to the lethal effect, for in both these cases the weevils with the live wheat were rendered motionless several hours (perhaps as much as 24 hours) before those in the corresponding cylinders with killed wheat. The effect of the wheat, however, appears to be much less than that of the weevils themselves with the quantities employed in these experiments; indeed, with the larger numbers of weevils the effect of the wheat appears to have been completely swamped, though it might possibly have been detected had the cylinders been examined at more frequent intervals.

General Conclusions.

It appears probable, at first sight, that the destruction of weevils in hermetically sealed vessels of wheat, definitely proved to take place by the experiments described in this Report, may be due to the action of carbon dioxide. That carbon dioxide does accumulate under the conditions of the experiments is easily demonstrated by passing the gases from one of the sealed flasks through baryta water. That it accumulates in considerable quantities has been shown by repeated analyses made for me by Mr. H. D. Elkington, who is now assisting me in these investigations. He has demonstrated quite clearly that carbon dioxide is produced in the flasks containing wheat both when weevils are present and when they are not, and the weevils themselves give off a surprisingly large amount. It has also been shown, in several distinct cases, that the weevils become torpid when the amount of carbon dioxide in the flasks reaches about 18 or 19 per cent. of the total air volume.

In this connection I may refer to the interesting work of Mr. F. Kidd (1914) on "The Controlling Influence of Carbon Dioxide in the Maturation, Dormancy and Germination of Seeds." This author shows that the germination is retarded or inhibited by high partial pressures of carbon dioxide in the atmosphere, and comes to the conclusion that the carbon dioxide acts as a narcotic. My observations on the grain weevils certainly suggest narcosis in this case also.

It is well known that dormant grain gives off small quantities of carbon dioxide in the process of respiration, the actual amount varying with the conditions of moisture and temperature, and the question of the part played by wheat and weevils respectively in bringing about the lethal effect in sealed vessels is touched upon in the account of experiment M.

It must be observed, however, that the results of the experiments described above might be explained as due either to increase of carbon dioxide or to diminution of oxygen in the sealed vessels, or to both, and there may even be other factors at work which have not yet been detected. Further experimental work is necessary in order to settle these questions and that work is now in progress and will, I hope, form the subject of a later report.

In the meantime I think it may safely be claimed that, within the limits of a wide range of conditions as to temperature, moisture and degree of weevilling, hermetical sealing is a very effective method of dealing with the weevil problem. The time taken to bring about the complete destruction of the insects seems to depend chiefly upon the relative volume of air present. Thus, if there are only a very few weevils in proportion to the air space they may go on living for a very long time, especially at low temperatures, but if the air space is kept down as much as possible by filling the receptacle full of grain it seems unlikely that weevils could ever accumulate in sufficient numbers to do much harm, for at low temperatures they are almost inactive owing to the cold, while at higher temperatures lethal conditions will probably arise so rapidly that the weevils will be destroyed before they have time to do serious damage. The importance of keeping the air space down is clearly indicated in Professor Zammitt's letter regarding the Maltese granaries. He says: "Should the granary be only half-full, and the grain already partly tainted by insects, it is advisable to place on the surface of the straw covering the wheat, an earthenware receptacle containing carbon disulphide."

The question will probably be raised as to the effect of air-tight storage upon the grain itself. Here again Professor Zammitt's testimony is very valuable. He says: "Grain thus stored can be kept indefinitely, the only evil effect of long storage being an impairment of the germinating power, which becomes torpid and irregular, if the grain is stored for more than two years. At the same time the bread-making quality of the grain is improved, *i.e.*, the bread-paste (dough) is more readily affected by yeast. Fermentation cannot take place unless the grain is heavily charged with moisture, from exposure to rain, or infiltration of sea-water on board ship."

In conclusion I may point out that in practice it would be of the first importance to see that the hermetical sealing of the silos or other receptacles was effectively carried out, as failure in this respect would almost certainly lead to disappointment. When once the initial difficulties of construction have been surmounted, however, the method of air-tight storage seems likely to prove extremely valuable wherever large quantities of grain have to be stored for long periods, especially in warm climates. It may also prove desirable, in cases where a long sea-voyage is involved, to store the grain on board ship in hermetically sealed tanks, and thus avoid the large amount of damage which, it is to be feared, sometimes takes place in transit. It should be remembered, moreover, that hermetical sealing would probably prove to be effective on a large scale, not only as a preventive measure, but also as a cure for badly weevilled grain.

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MAR-6 19

ROYAL SOCIETY.

REPORTS OF THE GRAIN PESTS (WAR) COMMITTEE.

No. 2.

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CONTENTS.

1. Bionomic, Morphological and Economic Report on the Acarids of Stored Grain and Flour. By Prof. R. Newstead, F.R.S., and H. Muriel Duvall, M.Sc.

2. Appendix I. Note on the Bacteriology of some Samples of Flour. By Prof. J. M. Beattie, M.D.

3. Appendix II. Report on Six Samples of Flour into which Mites had been introduced. By A. E. Humphries, Member of the Royal Commission on Wheat Supplies.

BIONOMIC, MORPHOLOGICAL AND ECONOMIC REPORT ON THE ACARIDS OF STORED GRAIN AND FLOUR,

By R. NEWSTEAD, F.R.S., Professor of Entomology,
and H. MURIEL DUVALL, M.Sc., University of Liverpool.

TABLE OF CONTENTS.

INTRODUCTION.

PAGE
Historical remarks 4
Species found 5
Technique 5
Arrangement 5

PART I.—MORPHOLOGY AND BIONOMICS.

Aleurobius farinae (De Geer) 6
Glyciphagus cadaverum (Schrank) 10
Cheyletus eruditus (Schrank) 10
Acarophenax tribolii gen. nov. et sp. nov. 20

PART II.—ECONOMIC AND EXPERIMENTAL.

Acarids in stored grain 26
  Kinds of wheat affected 26
  Influence of the seasons 26
  Methods of moisture estimation 27
  Methods of detection 28
  Conditions of existence 28
  Temperature 29
  Sources of infestation 29
  Nature of injury 29
  Prevention and remedies 30
Acarids in flour 31
  Nature of injury 32
  Conditions of existence 32
  The effect of hermetical sealing 33
  Effect of desiccation 33
  Prevention and remedies 34
Acarids in other cereal products 34
Conclusions 35

BIBLIOGRAPHY 35
EXPLANATION OF REFERENCE LETTERS ON PLATES 37
EXPLANATION OF THE PLATES 38
APPENDIX I 42
APPENDIX II 44

INTRODUCTION.

The work embodied in this Report has been carried out in Liverpool, which is an especially favourable centre in which to study the subject of acarid grain pests; not only is it the chief port of entry for the Canadian wheat most liable to the attacks of these pests, but it is also the largest storage and milling port in the United Kingdom. Hence it is possible to survey the wheat in ship, granary and mill, and also (what is of special importance in an investigation of this kind) to keep in constant touch with the requirements of the trade. Methods of prevention or cure which seem practicable enough when small quantities of grain and flour are dealt with in the laboratory may often be inapplicable to the enormous bulk of material, our chief foodstuff, which is handled by the trade.

Historical Remarks.

The occurrence of acarids or "mites" in stored grain, flour, fodder, seeds and other farinaceous foodstuffs has long been a matter of common knowledge. The pests often appear very suddenly in enormous numbers, owing to their powers of rapid reproduction under favourable conditions. Thus they have attracted the attention both of biologists and of persons engaged in the grain and flour trades. The harmful species infesting grain and flour belong to the family *Tyroglyphidae* and are few in number, and all the evidence points to their occurrence in the wheat of temperate countries only; within this limit, however, their geographical range is extremely wide, the same three or four species occurring all round the world. This wide distribution of a few species is probably artificial in the sense that it is due to the fact that their *habitat* is in commodities which have always accompanied civilised man in his wanderings and which at the present day are sent in great bulk from one country to another, both by land and sea. The reason they are not found in wheat from very hot countries such as India, is probably because of the low moisture content of such wheat, a condition, as will be seen later, quite inimical to their existence.

The following references to the work of authors in various countries will serve to indicate the wide geographical range of the pests :—

Russia.—Portchinsky, I. A. (14) notes the occurrence of *Tyroglyphus longior*, *T. siro* and *Aleurobius farinae* in grain, and the latter is said to be the most harmful. *Cheyletus* spp. are reported in dry hay and stored clover seeds.

America.—'Insect Life,' Vol. I, 1888–89, p. 51, and *ibid.*, p. 285. *T. longior* is mentioned as a grain pest occurring in association with *Cheyletus eruditus.*

France.—Moniez, R. (94), *T. longior* and *Aleurobius farinae* in flour.

Italy.—Berlese, A. (13), *T. longior* and *A. farinae* in flour.

Also in a report (17) on the acarids found on Charcot's Second French Antarctic Expedition, Berlese records: (1) the hypopial nymph of *Glyciphagus spinipes*, Koch; (2) the male of *Aleurobius farinae.* He notes, however, the possibility that the mites were introduced by accident into the collecting tube on the ship.

Species found.

We have found the following mites of the Tyroglyphid family in grain: *Aleurobius farinae* (De Geer), *Glyciphagus cadaverum* (Schrank), *Chortoglyphus arcuatus*, Troupeau, the last so rarely that it will not be referred to again. *Tyroglyphus longior*, Gervais, so constantly referred to as occurring in grain by the above authors, we have up to the present never come across. *Tyroglyphus siro* (Linnaeus) we have only once observed, in some wheat sent us by Prof. Dendy, the country of origin of which he was unable to tell us.

In flour the only acarid we have found is *Aleurobius farinae.*

Cheyletus eruditus is very constantly associated with the Tyroglyphids in grain and preys upon them, but its numbers are never so great. A species of Gamasid also occurs, but so rarely that this brief mention is sufficient. An interesting new acarid of the Tarsonemid family has been found; it is an ecto-parasite of the beetles *Tribolium confusum* and *T. ferrugineum.* An account of new morphological details, life-history and habits follows under the heading of each species.

Technique.

The life-histories have been worked out as the result of very tedious observation on isolated animals in breeding cells. After many trials the following breeding-cell was found to be most satisfactory; sections of thick glass tubing 1–1·5 centimetres wide and 2 mm. deep were cemented to a glass slide, the edges being finely ground; the cell thus formed was lined with black card, and all interspaces filled with paraffin wax run in hot; they were then covered with circular cover slips held in position by india-rubber bands.

Whole preparations have been made in glycerine jelly, Keilin's "mounting medium for dipterous larvae," and also by maceration in KOH followed by staining with carbol fuchsin and mounting in balsam. Many characters such as the hairs and the respiratory system are best studied when mounted in water or saline solution or even dry.

Satisfactory serial sections of *Cheyletus* were obtained by fixation in hot Bouin's fluid and embedding in paraffin (M.P. 52°). The best stain was found to be Mayer's glyc-haemalum followed by eosin.

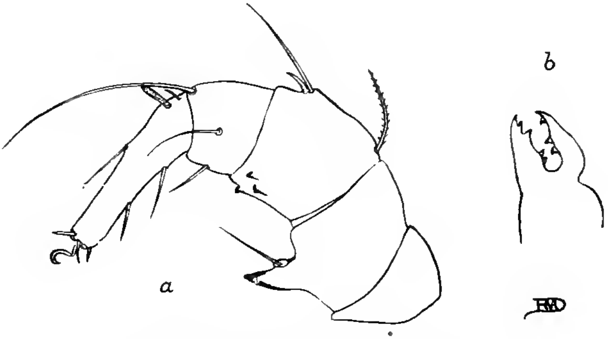
Arrangement.

The account of the work is arranged under two main headings: The first comprising descriptions of the morphology, life-history and habits of the species concerned, the second dealing with the more strictly economic aspects of the research, such as observations in the granaries, experimental work and preventive and remedial measures.

PART I.—MORPHOLOGY AND BIONOMICS.

ALEUROBIUS FARINAE (DE GEER).

This is undoubtedly the most serious and frequent of all acarid pests of grain and flour. It is also a common pest in cheese. The male and female are fully described and figured by Michael (01, p. 71) where full references to the previous literature are given. There is a slight discrepancy in his remarks on the genital suckers; he says in his account of the genus that they are present in both sexes, while in his account of the species he says they are absent in the female. We believe the latter statement to be correct. A paper dealing with the methods of combating the attacks of this mite on cheese has recently been published by Miss Eales (17).



Text Fig.—*Aleurobius farinae*, MALE.

a—first leg, dorsal aspect; *b*—mandible. × 330.

The Larva (Figs. 1, 2) which Michael does not describe, is here figured from the dorsal and ventral aspect. It presents no unusual features and bears two chitinous bars ("brustsstiele" of Claparède) just anterior to the epimera of the second pair of legs.

The first leg of the male (Text Fig., *a*) as is well known, is curiously modified and constitutes a characteristic of the genus. The second segment bears on its outer aspect a very stout pointed spine; in a notch at the base of the spine is a fine simple hair; on the same aspect of the third segment distally are three small chitinous teeth or papillae. Michael does not mention this hair but says " there are often two small teeth on the genual."

The mandible of the male is shown in Text Fig., *b*. It will be noticed that the teeth of one ramus are directed forwards whilst those of the other are directed backwards.

The *Hypopial nymph* is 0·16 mm. long. We have found the hypopus of *Aleurobius* on three occasions only; on two of these only one specimen occurred and on the third, when about 20 specimens were seen, it was during vacation with no available apparatus. It was, however, possible on the latter occasion to keep some of them under observation and to watch them change into nymphs and thus to be quite sure that they really belonged to the species. There was little doubt that the two single specimens found before belonged to *Aleurobius* as they occurred in cultures in which the only other acarids were *Cheyletus eruditus* and *Glyciphagus cadaverum;* the former species belongs to a family in which hypopi do not occur and the hypopus of the latter is well known.

Michael (03, p. 78) says that it is unknown to him. Canestrini (88, p. 201) gives a brief description of, but does not figure, a hypopus 0·2 mm. long with five pairs of suckers, the two last pairs of which are the smallest and the penultimate pair the largest. Berlese (82) says in his description of the genus, " Hypopi omnino ut in Tyroglyphis," and gives a figure, rather lacking in detail, in " Gli Insetti " (Berlese 12) remarking that it may be found on insects and other domestic arthropods. Oudemans (04. p. 207) describes and figures a hypopus which he then believed to be that of *Aleurobius* and which certainly very nearly resembles our specimens. We wrote to him on the matter and he informed us that he has since repudiated it, believing it to be, after consultation with Michael, the hypopus not of *Aleurobius* but of *Tyroglyphus longior*. Be this as it may, we are sure that our hypopus is truly that of *Aleurobius farinae* and herewith give as complete a description as the two specimens alone available for examination afford.

Form.—Dorso-ventrally flattened. Outline ovate, gradually and widely rounded posteriorly, and somewhat suddenly narrowed anteriorly between the first pair of legs to form a pointed rostrum.

Texture.—Slightly granular, not polished as in the other stages.

Colour.—A very faint pinkish brown. Portions of the sucker plate darker. The legs are the same colour as the body.

Dorsal aspect.—The cephalothoracic fold is well marked and is situated at a distance of about one-third of the length of the body behind the rostrum. There are four long finely-setose hairs on the cephalothorax arranged in a horizontal row across the middle of that section; four similar long hairs in series with the last just behind the cephalothoracic fold; two hairs midway between the last and the posterior margin; a short marginal hair between the first and second leg; two more on the shoulders; one behind each of the third and fourth legs, and two stout bristles on the posterior margin

The rostrum terminates in two papillae on which are borne two long stout bristles, between these dorsally are two finer bristles of the same length; two rather shorter pairs on the sides of the rostrum and a very short pair between them.

Ventral aspect.—There is a straight sternum; the epimera of the first legs are absent; the epimera of the second legs do not meet the sternum; the epimera of the third and fourth are curved. There is a minute hair on either side behind the fourth epimeron, a much longer pair just before the sucker plate and another more widely separated and smaller pair on the actual anterior margin of the latter plate. The sucker plate is curiously shaped and occupies the space between the last four segments of the hind pair of legs. In front of it is the genital orifice with two small suckers on either side; the plate itself bears four pairs of suckers arranged in series of two, four, two; the central pair of the second series being much the largest. There are three oval bodies, presumably glands, behind the plate.

The legs all have five segments, and one small curved tarsal hook. The chætotaxy is as follows:—The hind pair bear a very long bristle, as long as the body itself. The tarsi of all are remarkable for the varied character of the hairs or bristles, some being blade-like, others knobbed, others lanceolate. The rare occurrence of this hypopus is rather remarkable; we have had large numbers of *Aleurobius* under observation during two seasons under varied conditions of moisture, temperature and diet, and only on the three occasions mentioned above did it appear. The evidence in this species supports Michael's (01. p. 161) contention that the hypopus is a distributive form, and that its appearance is not caused by the onset of dry conditions or lack of food, the stimulus which determines whether any individual shall pass through this interpolated stage or not being entirely unknown.

Life-History and Habits.

The life-cycle of this species was worked out in the months of June and July at a temperature varying from 64°–71° F. We found that the essential condition of a moist atmosphere was better attained by keeping the air surrounding the breeding cells saturated rather than by placing a piece of moist blotting paper in the cell itself, although the latter plan is the one adopted by Michael and other observers. In captivity the gravid female lays from 20 to 30 eggs, scattering them promiscuously over the food and the walls and sides of the cell;

she deposits three or four each day. In the act of oviposition the extruded egg is grasped firmly by the hind pair of legs, pushed behind the body and left.

The egg measures 0·12 mm. long by ·08 mm. across and is oval, white, and smooth. Although uniformly opaque when first laid, as development proceeds the broader end of the egg becomes transparent. The incubation period is three to four days; at the end of this time the hexapod larva escapes by an irregular rupture of the chorion, which is left absolutely transparent and very iridescent. The larva feeds and grows rapidly for three days and then becomes inert for one or two—lying motionless at this time on its venter with legs drawn up, the body having a characteristic inflated "full-fed" appearance. The larval skin then splits dorsally and the young nymph emerges after some struggling to free itself from the cast. The nymphal stage lasts from six to eight days, two of which are spent inert in preparation for the final ecdysis. *Aleurobius* is rather exceptional in undergoing only one nymphal stage, two being the more usual number among acarids. The adults copulate on the day or day after ecdysis and eggs are laid two or three days after coition.

The complete cycle from egg to egg may thus be accomplished under favourable conditions in 17 days, but in experiments conducted during the winter months (temperature 50°–60° F.) it took 28 days, both the incubation and nymphal periods being prolonged. Under these conditions the females do not appear to lay so freely. Copulation is effected by the male partly mounting the back of the female in such a manner that the hind quarters of the pair are in contact and their heads in opposite directions, the penis is then in the correct position for insertion into the *bursa copulatrix* of the female. The male is enabled to get a firm grip of his consort by means of the anal and genital suckers and the suckers on his hind legs. Coitus is maintained for several hours, during which a nuptial promenade is kept up, the female taking the direction and the male walking backwards. The male sometimes pairs with several females, but in many observed cases he died after a single performance of this function.

Mode of Injury to the Grain.

Aleurobius attacks and injures sound wheat berries in the following way:—A small hole is bored in that portion of the epicarp which overlies the embryonic region. Mites then enter and devour first the embryo and its surrounding tissues and later the endosperm, until little is left but the hollow husk, which may be occupied by as many as 50 individuals. This mode of attack was described by Michael (03. p. 79) and we have been able to confirm it. Fig. 27 (Plate IX) is a photograph of grains injured in this way contrasted with sound ones.

GLYCIPHAGUS CADAVERUM (SCHRANK).

Glyciphagus cadaverum occurs in most parcels of wheat which contain *Aleurobius*, but in smaller numbers. It does not seem to attack sound wheat, but lives on broken grains and *débris*. It is very active and hurried in its movements and is a really beautiful microscopic object with its long plumose hairs and brisk motions.

The species we have found is exactly like Michael's *Gl. spinipes* (01. p. 245) except in the absence of the setose scale on the genual of the third leg of the female. Oudemans (04. p. 214) considers Michael's *Gl. spinipes* to be an insular form, and renames it *Gl. michaelis*, the form without the setose scale he considers to be *Gl. cadaverum*, Schrank; the name *Gl. spinipes* therefore lapses.

Life-History.

This has been difficult to work out owing to the delicacy of the young stages and their habit of passing the inert periods buried in the food. An approximate time-table is as follows: Incubation period, three to four days; larval period, four to five days, of which the last two are spent inert; nymphal period about eight days; (whether this takes place in one or two stages we have not been able to make out with certainty). The female lays eight or ten smooth narrowly oval eggs deep among the foodstuff or in some convenient cranny.

The hypopus is very frequent and often occurs in swarms; it is a degraded type and never emerges from the nymphal skin, depending upon the wind for distribution. It is fully described by Michael and by Oudemans in the two papers last quoted.

CHEYLETUS ERUDITUS (SCHRANK).

This extremely interesting acarid belongs to the *Cheyletidae*, a family characterised by the extraordinary development of the pedipalps and their separation in connection with their raptorial functions from the other mouth appendages. Although previous observers, attracted no doubt by its interesting manners and customs, have from time to time recorded observations both of its external structure and of its habits, it has been, we hope, worth while, particularly as the opportunity for study presented itself, to verify and add to their observations. The life-history has been worked out exhaustively in the present research and the reproduction by parthenogenesis definitely proved. This last fact was also observed by Beck (66) as long ago as 1866, with whose little-known paper, however, we only became acquainted at the close of our own observations. We believe that the internal anatomy of the *Cheyletidae* has not heretofore been investigated, and the compact and relatively simple form of the genital organs seems to be peculiar. The external characters of a *Cheyletus* which they believe to be *eruditus* have been rather fully described by Fumouze and Robin (67). These authors, however, labour under the misconception that the creature they are dealing with is a nymph, whereas it is really the adult, not even of *Cheyletus eruditus*, but according to Oudemans (03) of a closely related species *Cheyletus sneiderei*, Oudemans. In this paper Oudemans gives a full review of the previous literature of the species which is not repeated here.

Habits and Life-History.

Cheyletus eruditus occurs in most grain samples which contain Tyroglyphid mites, and its distribution is probably quite as wide as theirs. Like most predatory creatures it is solitary and does not herd together in masses as do its Tyroglyphid victims, and it never, luckily for them, becomes nearly so plentiful.

It is very doubtful if it is ever sufficiently abundant in nature effectively to reduce Tyroglyphids when they occur in such numbers as to form a pest, although marvellous powers are claimed for it in this connection by a writer in 'Insect Life' (Vol. I., 1888–89, p. 51). In that case the reason for the disappearance of *Tyroglyphus longior* is more likely to have been the continuous drying of the parcel of wheat, but as the moisture conditions are not stated, this suggestion cannot be tested. Experiments carried out in the laboratory during the present research with small quantities of wheat have demonstrated that the presence of *Cheyletus* is ineffectual to prevent the rapid multiplication of *Aleurobius farinae* under favourable conditions of temperature and moisture for the latter. All the same *Cheyletus* is a veritable tiger among the peaceful browsing herds of Tyroglyphids and its purposeful rapid motions are in marked contrast to the aimless hurry of *Glyciphagus cadaverum* and the leisurely crawl of *Aleurobius farinae*. It can run backwards with ease and rapidity should it deem a sudden withdrawal prudent, as when, for example, a small individual meets a larger one of its own species. Though without eyes it seems intensely aware of events in its neighbourhood, owing no doubt to the large numbers of tactile hairs and sense-rods with which the legs are equipped; the ambulacra, too, with their delicate suckers must help the creature considerably to a knowledge of its immediate environment. When feeding, *Cheyletus* seizes any part of the victim between its curved pedipalps which then close like pincer-blades towards each other with a grip from which there is no escape; the stylet-like mandibles are then used to pierce the cuticle, while powerful pumping motions of the pharynx effect the transference of the body juices of the victim to its own gut. After the meal the empty shrivelled skin is cast aside. During the repast the pectines of the pedipalps are in contact with the skin of the victim and bent down at right angles to their normal position. It is noticeable that the prey always becomes paralysed a few moments after capture, probably because some poison secreted by the large so-called "salivary gland" is injected. In captivity *Cheyletus* is a shocking cannibal, and this habit commences from hatching, the larvæ generally making their first meal off an egg of the same batch, while the nymphs will devour both larvæ and each other, and adults will eat both eggs and other stages. When the victim is of its own kind little or no paralysis occurs, *Cheyletus* is evidently immune to the specific poison.

Several successive generations of *Cheyletus* have been bred in captivity during the year but neither in these cultures nor in its natural environment have we ever come across a male animal. On the other hand females reared in captivity and isolated from the egg or from hatching, have produced fertile eggs, from which in turn other generations have been bred. Beck (66) describes the same phenomenon of "agamic" reproduction in an acarid which from his account is without any doubt *Cheyletus eruditus.* His observations were carefully carried out and our own confirm them. Thus the occurrence of parthenogenesis, stated in so many text-books to be non-existent in the Acarina, must be regarded as proven. Of course it is possible that males may appear under certain conditions, or they may be periodic as in the aphids. Oudemans (03) indeed describes a form which he calls the male of this species, but he repudiates this in a later paper (06), where he figures another form which he considers to be the male. The latter only differs from the female in size and in the possession of two extra pairs of hairs on the anterior dorsal shield. The genital orifice is, he says, minute and surrounded by three pairs of small curved bristles, a description which applies equally well to the anal papillae of the female. The sex can hardly, we think, be regarded as fixed by these small characters, unsupported as they are by any functional evidence.

Parthenogenesis has been suspected in other acarids, notably in certain Gamasids, but Miss Anna Foa (00) has in all these cases identified the males. In regard to these and other suspected cases, Banks (13) remarks: "There is therefore no positive proof of parthenogenesis in the acarids."

The eggs of *Cheyletus* are laid in batches of from 20 to 30, often in the longitudinal groove of the wheat berry or in any available cranny. At the commencement of the laying period an egg or two is generally deposited promiscuously and then the main batch is laid in one or two days. The female broods over these until they begin to hatch out, adopting a threatening attitude to any intruder. Should the latter venture to approach more closely he is vigorously attacked in a manner most amusing to watch. The female does not quit her brood in search of food, but subsists on what prey may come within reach. By a curious perversion of instinct this otherwise model mother sometimes devours her own eggs. After leaving the batch of eggs she may survive for some weeks and lay a few more eggs every now and again. These "spent" females become very dark in appearance and ultimately shrivel and die. Breeding goes on all the year round, but the life-cycle is much prolonged in cold weather. Shortage of food also undoubtedly lengthens the life-cycle, particularly in the nymphal stages.

Cheyletus can survive long periods on very short rations; we have often found them alive, though emaciated, in stocks of wheat which had become too dry to contain any living Tyroglyphids.

The average period from egg to adult is probably 36–40 days. The following are the durations of the various stages in a specimen reared in June at a temperature between 55°–56° F.

Incubation period	4 days.
Larval period	10 days (4 spent inert).
1st nymph	7 days (3 spent inert).
2nd nymph	15 days (3 spent inert).

This young female laid eggs five days after emergence (an exceptionally short period). The variability in the duration of the various stages caused by temperature or other factors may be gathered from the following summary taken from our breeding time-tables:—

Incubation period from 3 days in June to 15 in February.
Larval period, 5 to 10 days.
1st nymphal period from 5 to 17 days.
2nd nymphal period from 7 to 20 days.
Period between last ecdysis and first egg laid, 13–17 days.

In the same way the time spent inert between the stages is also very variable, it may be as short as two or as long as seven days.

External Anatomy.

The egg is 0·15 mm. by 0·1 mm. broad. It is broadly subovate, and the head of the embryo develops at the broad end. The surface of the egg is smooth and when first laid of a uniform opaque white appearance owing to the even distribution of the yolk granules, but as development proceeds its broader end becomes transparent.

Development.—As much as can be seen of this without sections has been described by Kramer (81).

The Larva (Fig. 3) measures, when just hatched, 0·23 mm. from the tip of the rostrum to the hind margin, and when full fed 0·32 mm. It is hexapod and differs from the nymphs and adults in the following points:—

The dorsal shields are not clearly defined; there is only one pecten or comb on the pedipalps; the terminal bristles of the first pair of legs are uneven in length. The dorsal hairs are few and not visibly plumose; the four feathers of the posterior margin are relatively conspicuous and much flattened. The chætotaxy of the ventral surface is as follows: tibia of pedipalp, two hairs; coxa I and II, one hair; on the body itself a pair between the two first legs, and another pair on a level with the third legs; one pair of long hairs on the posterior margin;

one long outstanding hair on each lateral margin between the second and third legs. The chætotaxy of the legs and dorsum is shown in the figure.

The Nymphal Stages.—These have been fully described by Oudemans (03), therefore it is only necessary in this paper to make a few additional observations and to note where our description differs from his.

The First or Protonymph is smaller when it first emerges than the full-fed larva, measuring only 0·25 mm. When full fed it is 0·39 (one as long as 0·44 mm. has been measured). The large pecten of the pedipalps has 10 teeth and the smaller one six. We find not two but only one hair on coxa I, and on patellae I, II, III two hairs each, not one as Oudemans says.

The Second or Deutonymph measures when full-fed 0·54–0·578 mm. (a very small one 0·51 mm. was once noted). There are 10 teeth on the large pecten and 12 on the small.

The Adult.

Measurements.—When newly emerged 0·69–0·71 mm., when full grown 0·765 mm. On emergence the young female is at once active and feeds voraciously; her growth is very rapid and the body which is at first dorso-ventrally flattened soon becomes much swollen and arched dorsally. A young adult can easily be distinguished from a nymph by the proportionately larger capitulum and pedipalps.

The general features of the external anatomy have been described by Oudemans (03) and we differ from him only in the following small particulars: The outer of the two hairs on the ventral surface of the femur of the pedipalp is plumose, the inner smooth; there are five hairs on tibia I and four on tibia II, III and IV and not two on each; the patellae and femora all bear two hairs and not one. The cephalothoracic fold is well marked dorsally and lies between the third and fourth legs. The pillars of the dorso-ventral muscles show as small circular clear areas in freshly mounted specimens; there are three pairs of these on each side about half-way between the lateral margin and the middle line and arranged in a longitudinal series, the first pair opposite the outstanding lateral hair; the second opposite the fourth leg, the third pair midway between the second pair and the posterior margin.

The Pedipalps (Figs. 8, 9).—These are shown from the dorsal and ventral points of view. The coxae are said to be fused to form the under-surface of the capitulum; the trochanters are very short and better seen on the ventral than the dorsal surface; the large pecten bears 14 teeth and the small one 16; there is a very short spine on the tarsus in addition to the two large curved spines.

The Tarsi of the walking legs are each provided with a complex ambulacrum, and probably have tactile as well as locomotor functions. Figs. 5 and 6 are drawn from the third leg and they apply also with little modification to the second and fourth leg; the first leg has a different arrangement (Fig. 7). The tarsus of the third leg terminates in a flexible "fetlock" which carries distally two strong recurved claws; between the claws and borne upon a chitinous ring-shaped framework, are two ranks of three to six very small suckers, forming the pulvillus. From the proximal end of the fetlock spring dorsally two strong curved bifid bristles (*b.b.*) which in life appear to touch the claws, and ventrally there are two fine plumose hairs (*h.h.*). The tarsus itself bears ventrally somewhere near its centre a long plumose "supporting bristle" (*s.b.*) reaching to the fetlock, and dorsally two simple terminal bristles as long as the tarsus itself. The tarsus of the first leg (Fig. 7) is longer and more slender than the others: its two terminal bristles are nearly twice its own length; in addition to the ventral supporting bristle and opposite it on the dorsal surface there is a short thick sense rod (*s.r.*); two fine plumose hairs spring alternately on either side from the distal end of the tarsus and extend to the claws; a single curved bifid bristle on one side is inserted at the base of the "fetlock," followed by a shortish plain blunt spine inserted lower down on the same side, and on the other side a longer similar spine extending beyond the ambulacrum.

Vulva and "Anus" (Figs. 11, 12, 13).—The so-called "anus" is really the orifice of the excretory vessel and the excreta are therefore not fæcal but crystalline bodies, probably urates; moreover the vulva and the "anal" orifice are continuous. In the adult (Fig. 13) the vulvo-anal orifice is a longitudinal slit situated in the middle line on the ventral surface, commencing from a point about midway between the posterior margin and the coxae of the fourth legs, and extending to the tip of the "anal" papilla. It resembles a long button-hole when viewed from the surface. The spherical object seen at the top of the buttonhole (Fig. 13) is shown in sections to be chitinous and projects into the vagina just before this opens into the anterior part of the cloaca. The vulvo-anal orifice is seen in section in Fig. 16 (*v.a.o.*). It is flanked by four stout bristles on each side. The so-called "anal papilla" is furnished with two pairs of stout recurved bristles or hooks and one pair of longish fine hairs—not as Oudemans says with three pairs of curved hooks. These hooks are not present in the immature stages and presumably are connected with oviposition. In the larva and nymph (Figs. 11, 12) the orifice is similar, but proportionately much shorter. In the larva there are two very long hairs on the posterior margin. The "anal" papilla is retractile and many preparations, especially of the larva and nymphs, were required before its relationships could be correctly established.

The Mouth Parts have been described by Fumouze and Robin (67) and also by Kramer (76). They form a pointed rostrum or snout, and consist of a pair of long blade-like mandibular stylets lying each in a long sheath. From this sheath the stylets can be protruded for a certain distance (Fig. 10, *md.*, where they are shown protruded);

ventrally there is a sword-shaped median hypostome or "languette" at the base of which opens the mouth encircled by a chitinous "mouth ring." Enclosing the mandibles, but free of them, are two curved, jointed side pieces which bear a single bristle dorsally and ventrally.

Internal Anatomy.

The Epidermis consists of a superficial chitinous layer secreted by an underlying single layer of squamous epithelial cells. Some of these squames are shown in Fig. 19; they are polygonal with faint nuclei and stained with eosin. The cuticle is thin and finely plicated over most of the ventral surface of the body, the sides, and between and behind the two thick plain dorsal shields. The cuticle of the legs of the rostrum and of a small area round the vulvo-anal slit is plain. The directions of these plications in the posterior ventral regions are shown in Figs. 11, 12 and 13.

The Respiratory System (Fig. 10).—This can only be studied in very fresh whole preparations in water, glycerine or Keilin's mounting medium, the degree of visibility being attendant on the presence of air in its different parts. There is a pair of lateral marginal stigmata (*a.s.*) situated at the base of the rostrum a little in front of the angle where the latter meets the pedipalps. The median pair (*m.s.*) are found a little further back in the mid-dorsal line. Under normal conditions the openings face one another as they lie on the sides of a groove in the integument at this point, and for this reason they are not easily seen unless the fold is smoothed out (perhaps this is why Oudemans denies their existence). A hollow five-jointed and highly chitinous air-tube curves round on each side and connects the two stigmata, and the two limbs thus form as it were a kind of collar lying close under the dorsal surface (*co.*). In addition a similarly constructed six-jointed tube (*l.e.*) leads directly back from the lateral stigmata on each side and ends at about the middle of the coxa of the pedipalp. A very small orifice (*p.s.*) connects the interior of the last segment of this lateral air-tube with the surface.* These very peculiar air-tubes are called "peritremes" by Oudemans (03), they are however clearly not comparable to the structures of that name found in the Ticks and Gamasids. He appears to have overlooked the fact that they are tubular and probably endowed with a supporting function, and so arranged that a supply of air by one or other of the stigmata on each side is always maintained. From each median stigma a main tracheal trunk (*t.t.*) is led off, curving at first forwards and then backwards and dipping ventrally until it breaks up behind the capitulum into a fascicle of fine tracheal tubes leading to all parts of the body, capitulum, and legs; this trunk has a curious jointed appearance at a point about one-third of its length in the capitulum. From the lateral stigmata three fine tracheae run back together and come to lie along the course of the main tubes. Each leg receives three or four tracheae, only one of which reaches the tarsus. The tracheae terminate in little dilated bulbs (*cf. Acarophenax*), they do not anastomose or branch after leaving the main tracheal vessel. We can find no trace of taenidae in the walls of any part of the system, but Fumouze and Robin (67) say that the large vessels possess them.

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* In the larva and first nymph each limb of the collar has four segments and the lateral continuation five. In the second nymph there are four segments to the limb of the collar and six to the lateral continuation.

The Alimentary Canal.—This consists of pharynx, œsophagus, ventriculus and three pairs of cæca. There is no hind-gut, rectum or anus. A large " salivary " gland discharges into the mouth.

The Pharynx is a pumping organ and has very thick chitinous walls, it runs back from the mouth close to the ventral surface, where its lower border is curved widely outward on each side along its whole length to form the floor of the capitulum. It is shown in section (Fig. 17 *ph.*). The lumen is very small, but is capable of enlargement by the series of powerful muscles inserted along its length (*m.ph.*). It runs back almost to the brain, increasing in dorso-ventral dimensions as it goes until it narrows suddenly where it enters the œsophagus through a chitinous valve.

The Œsophagus is a narrow thin walled tube which takes a diagonal course through the brain from the point where it enters the latter organ on the ventral surface and just behind the anterior prolongation, to the point where it issues dorsally. Its position in longitudinal section is indicated by the broken line in Fig. 20 (*oe.*) and it is shown in cross section in Fig. 18 (*oe.*).

The Mid-gut (Fig. 4).—After leaving the brain the mid-gut widens to form the ventriculus, or stomach, which extends forward in a median prolongation as far as a line between the attachments of the first and second legs and backwards to end blindly behind just in front of the level of attachment of the third pair of legs. It gives off three pairs of cæca ; one pair (*cæ.* I) running forwards on either side of the salivary gland and extending into the capitulum as far even as the femora of the pedipalps ; a second median pair (*cæ.* II) occupying the area between the attachments of the second and third legs ; the third posterior pair (*cæ.* III) curve backwards round the lateral hinder margins and meet, but do not coalesce, at the posterior extremity. Prolongations of the cæca extend a short distance into the legs. The walls of the ventriculus and its cæca are very delicate and tenuous ; and consist of a layer of rather small cubical or rounded cells. The contents of the lumen are fat globules, disintegrated cells, nuclei, &c. The position occupied by the mid-gut and its cæca at various levels is shown diagrammatically in transverse section in Figs. 14, 15, 16 (*cæ.*).

The Salivary Gland (Figs. 17, 20 *s.gl.*).—This is a large body, lying above the brain in the fore-part of the body. It extends backwards to about the level of the ovary and appears to be prolonged forwards as far as the commencement of the rostrum. It is separated from the brain posteriorly by the ventriculus, but it comes to surround that organ entirely further forward. It appears as a clear area in whole fresh preparations. On either side of it the main tracheal trunks pass backwards (Fig. 17 *t.t.*) and the anterior pair of digestive cæca forwards. The gland consists of a few very large cells, closely packed for the most part with large eosinophilous granules. The nuclei are ill-defined, and there is generally a finely granular lenticular-shaped body clearly marked off from the rest of the cell contents. The appearance of these cells differs somewhat in different preparations, probably according as they were or were not in active secretion at the time of fixation. The duct we have not been able to define with certainty, probably it opens into the mouth. One must suppose that this is the gland possessed of the paralysing qualities formerly alluded to (p. 11).

The Excretory Organ (Figs. 4, 14, 15, 16 *exc.*). This is a long vessel which lies close to the dorsal surface along the middle line. In life it appears as a white stripe owing to the nature of its contents, which are white by reflected light. It extends forward to the level of the attachments of the first pair of legs where it overlies the salivary gland and is supported by two strips of muscle inserted at the base of the rostrum. Behind it just fails to reach the posterior margin and in this region its floor dips downwards between the hindmost digestive cæca and the accessory gland to the opening into the cloaca. The size of the lumen and the appearance of its walls vary very much in different preparations according to the amount of the contents and the secretory activity of the cells at the time of fixation. It generally contains a number of small refractive crystalline bodies, white by reflected and black by transmitted light, which are insoluble in alcohol, ether, xylol, and water and are probably urates; they are voided by the creature every few days. This organ has no connection whatever with the gut; it is therefore similar to that described by Michael (95) in *Thyas petrophilus*. In this paper Michael discusses the homologies of the excretory organ at length and summarises the opinions of authors on this much-vexed question.

The Nervous System (Figs. 18, 20, *n.s.*).—As usual among the Acarina the nervous elements are fused to form a central ganglionic mass, traversed by the œsophagus, which is known as the brain or nerve-mass. It lies in the ventral half of the body commencing about the level of the insertion of the first pair of legs and extending backwards some way beneath, and also a short distance above the ovary. In longitudinal sections (Fig. 20 *n.s.*), it has a roughly pyriform shape, the anterior end projecting in a narrow process. A similar extension is noted by Michael in his paper on the brains of acarids (95), as occurring in the Gamasidæ; he there figures a longitudinal section of the brain of *Cheyletus flabellifer*, in which however the extension is much shorter than in *Cheyletus eruditus*.

There is a well-defined cortical layer consisting of small nuclei;

this layer becomes thin or absent at the posterior dorsal surface round the part where the œsophagus emerges. The layer presents a scalloped or festooned outline towards the centre, and within this the protoplasm is finely granular and divided into distinct lobes or areas (Fig. 18). We have not been able to trace any of the nerves.

The Genital Organs.—These are of the female only and consist of ovary, paired oviducts, vagina, and a single large accessory gland, grouped together to form a compact mass which occupies a large part of the ventral half of the body.

The Ovary is peculiar and differs from that of any acarid heretofore described. It is shown in transverse section in Fig. 14 and in longitudinal section in Fig. 20. From a careful study of serial sections it appears to consist of an inner solid mass (*i.m.*) of cells surrounded by an outer unicellular layer (*o.m.*). Between these two is the narrow lumen, but the inner mass becomes continuous with the outer layer anteriorly. By this arrangement there is secured an increase in the extent of surface from which eggs may be extruded. The youngest ova or oocytes are found in the anterior and central portions of the inner mass, the maturing ova are situated on the posterior surfaces.

The Oviducts (Fig. 15, *ovd*) leave the ovary on each side posteriorly and dorsally, and appear to take a course downwards and backwards coalescing ventrally beneath the accessory gland to form the short median vagina. The chromatin in the oocytes is in the spireme stage, but in the more mature ova it is gathered up into a single large nucleolus. When in the oviducts the eggs become very large and filled with yolk granules, but no signs of segmentation are discoverable while they are still within the mother's body; the developmental stimulus must occur either at or after oviposition.

The Accessory Gland is situated posterior to the ovary and is a compact kidney-shaped body. It is seen in longitudinal section in Fig. 20 (*a.gl.*) and in cross section in Fig. 15 (*a.gl.*). It is made up of a single layer of radiating columnar cells. The nuclei are arranged in a regular manner just within the periphery of the gland, but the cell boundaries cannot be distinguished. In the nymphs this gland is solid, but in the females when the cells become active it develops a lumen which increases from in front backwards. The lumen becomes merged with that of the excretory vessel and so joins the common cloaca into which also the eggs are passed. In mature animals the lumen is filled with a copious haematein-staining secretion (Fig. 20, *s.agl.*) and as the chorion of the egg also takes this stain, it does not seem unreasonable to suppose that its function is the formation of the egg covering.

A New Viviparous Acarid of the Family Tarsonemidae.

ACAROPHENAX, *gen. nov.*

Diagnosis.—Female without pseudo-stigmatic organ and with the stigmata in two pairs: anterior pair marginal, posterior pair dorsal.

Claws on legs II, III and IV absent in both sexes. Respiratory system absent in male.

Type.—*Acarophenax tribolii.*

ACAROPHENAX TRIBOLII, *sp. nov.*

Bionomics.

This mite is an ectoparasite of the grain beetles *Tribolium confusum*, Fab. and *Tribolium ferrugineum*, Duv. Prof. Dendy, F.R.S., who is conducting investigations on the insect pests of grain, first observed the creature in some numbers upon the bodies of some of the beetles in his cultures and sent the material to us for investigation. The beetles originally came from a sample of Australian wheat, but had since been fed on other kinds of wheat before the parasite was noticed. We have since found the mite on *Tribolium ferrugineum* from a badly weevilled sample of Plate maize.

Tribolium does not attack sound grain and must therefore be supplied with crushed wheat; it breeds freely at a temperature of about 30° C. at which our cultures were kept.

The mites are often to be seen upon the bodies of the beetles, and appear to be able to attack their hosts where the cuticle is thin between the joints, but most of them ultimately find their way beneath the flight wings where the large area of soft cuticle on the dorsal aspect of the abdomen offers little resistance to their minute, piercing and sucking jaws. Almost every beetle in a culture appears to become infested and as many as 31 parasites were once counted upon a single beetle, 10 or 12 is, however, a more usual figure. The infestation does not seem to be in any way detrimental to the host, breeding and feeding continuing undisturbed. The beetle larvae are not apparently liable to attack by the mites, but large numbers have been observed on the underside of the pupæ. The acarids found upon the beetles and pupæ, and many hundreds of them have been examined, are always of one form (Figs. 21, 23), they are, indeed, young females.

This fact was at first very baffling to us in our efforts to work out the life-history, as although the parasites were obviously increasing in our cultures, we could for some time discover no other stages. At length, however, a small spherical body was discovered amongst the frass, which proved to be our acarid, but with a now enormously distended abdomen. This specimen was isolated and watched, and after two days it became transparent and movements were discernible within. A hole then appeared upon the ventral surface of the hinder portion of the body and from this emerged 10 individuals of the same form as those which were found upon the beetles, and which, when a *Tribolium* was introduced into the cell, were observed to mount upon it and later to disappear under the elytra. Many distended specimens have since been found and observed; they are always attached to the eggs of *Tribolium* from which they suck all the juices, so that infested eggs become collapsed. As many as seven have been seen upon a single egg, but one is the more usual number. The distended forms vary a good deal in size and may produce from 4 to 15 young individuals, among which there is generally one male (Fig. 22), all the rest being females. The male has not been seen in every case, but in no instance has more than one been obtained from a single parent.

It is probable that the male fecundates the young females before they leave the parent body, as he is generally to be found dead either within or just beside the latter after the departure of his consorts, and has never been seen upon the beetles or their eggs. The newly-emerged females are very active and when kept in small cells for observation refuse to parasitize at once the eggs of *Tribolium*, but readily attach themselves to the beetles, so that it would seem that a preliminary period upon the mature host, although unaccompanied by growth, is necessary for proper development, and that the migration to the egg only takes place after this has been accomplished. It is certain from our observations that a long period may be passed upon the beetles and that a good many individuals never leave them and ultimately perish in that situation. In our large cultures, specimens ranging from very slight to full distension have been seen upon the eggs, and we have in our breeding cells been able actually to observe the migration from beetle to egg and to trace the subsequent growth to maturity and production of offspring upon two occasions. The distended stage passed upon the egg lasts generally about three days during which growth is very rapid, the female becoming more and more unwieldy and finally incapable of walking, although she makes feeble movements of the legs; on the third day she dies and the young females emerge through a hole which corresponds in position to the genital orifice, but which they enlarge for themselves. All the young stages are in this way passed within the mother's body, apparently without ecdyses and in a telescoped manner, the creatures emerging as perfect animals and leaving the parent's body a mere transparent shell, empty save for the remains of the excretory organ and the tracheae.

This life-history resembles that of *Pediculoides ventricosus*, Newport, as described by Brucker (01) in his memoir on this animal. In *Pediculoides ventricosus*, however, the mother brings forth her young, which are perfect males and females, at intervals of several days and continues to feed as she does so. In her case too the distention is confined to the posterior end of the body, whilst in the species here described the whole of the dorsum becomes distended and arched, as is also stated to be the case in *Pediculoides tritici* (Reuter 00) a purely vegetable feeder and the cause of "silvertop" in grasses.

Morphology.

The Female (Figs. 21, 23, 24, 25, 26).—*Shape* in life of the young females, pyriform, tapering somewhat suddenly towards the posterior extremity from a point a little in advance of the middle of the body.

This appearance is lost in mounted preparations where, owing to the pressure of the cover glass, the body has the broadly subovate outline seen in the figures. The dorsum is highly convex. The anterior margin of the dorsum is produced forwards between the lateral stigmata to form a hood beneath which the mouth parts are completely hidden from the dorsal aspect. The distended females are nearly spherical, flattened on the ventral surface.

Size.—The parasitic young females measure from 0·16 to 0·19 mm. from the tip of the rostrum to the posterior margin. The distended forms 0·24 to 0·29 mm. in diameter.

Texture.—The young ones are glossy but the old ones while smooth are not polished.

Colour.—A faint yellowish tinge.

The Dorsal Aspect (Fig. 23).—There is a definite cephalothoracic suture or fold situated immediately behind the insertion of the second pair of legs. The excretory organ shows as a broad white band along the mid-dorsal line, as in *Cheyletus.* Behind this the abdomen exhibits definite though faint traces of the segmentation characteristic of the Tarsonemidae. Five segments is the most usual number, but there are sometimes more. There are five pairs of simple hairs situated as follows: the first pair just behind the rostrum, the second pair near the margin and midway between the line of insertion of the first pair of legs and the cephalo-thoracic suture. The third, fourth and fifth pairs are well within the margin and arranged in a longitudinal series nearly equidistant from each other. Between the fifth pair is another very short pair.

The Ventral Aspect (Fig. 21).—There is a simple outstanding hair on each side inserted just within the ventral margin in a line with the cephalothoracic suture, its length being slightly more than half the width of the body at this region. In addition, there are six pairs of hairs of varying length, the first two pairs on the same level just in front of the insertion of the third pair of legs; the third pair in front, the fourth pair behind the insertion of the fourth legs; the fifth pair are longer and much nearer the middle line, and the sixth pair very small on either side of the transverse genital orifice. There are two pairs of short hairs on the posterior margin. Between the third pair of ventral hairs is a pair of short stout spines. There is a well-marked skeletal collar which meets the central sternum and to which also the epimera of the second pair of legs are connected. The epimera of the first pair of legs are free of the sternum and those of the third and fourth pairs do not reach the middle line. There is a faintly indicated transverse fold between the second and third legs and another just behind the fourth.

The Mouth Parts are in camerostome. They are extremely minute and appear to be reflexed backwards when at rest. The mandibles are stylets and the pedipalps though jointed, are rudimentary.

The Legs.—The first and second pair are directed forwards and widely separated from the third and fourth, which are directed backwards.

The first pair is much more robust than the others and consists of four segments only (indications of a rudimentary fifth segment have been seen in some specimens). The first three segments are sub-equal in length and nearly as broad again as long; the fourth segment is characteristically incrassate, being broader and more than twice the length of the others; it bears a minute strongly recurved claw, a short transversely striated lanceolate spine on the outer lateral margin, three long hairs and a few shorter ones. There are three long hairs on the third segment and one short one on the second. Lateral chitinous plates are found on the three distal segments.

The second pair of legs consists of five sub-equal segments, with lateral chitinous plates on the last three. The tarsus bears a sucker carried at the end of a peduncle which is longer than the tarsus itself; there are two lanceolate spines at the base of the peduncle and one on the outer lateral margin, and two longish hairs; one long hair on the third and fourth segments respectively.

The third and fourth pair of legs have five segments and are less robust but longer than the third; they are alike except for a very long terminal bristle, rather longer than the leg itself, which is borne by the fourth pair. Each pair has a pedunculate sucker, at the base of which are two lanceolate spines, and there is one long and one short hair on the fourth segment.

All the above characters can be made out in the distended females (Figs. 24, 25), and it is therefore improbable that an ecdysis occurs between the parasitic and distended state.

The Respiratory System (Fig. 26).—The stigmata are in two pairs. The anterior pair is marginal and situated at the base of the hood, the posterior pair lie directly behind the first upon the dorsal surface (*r.s.* and *d.s.*). The anterior and posterior stigmata on each side are connected by a stout tracheal trunk which runs a short way back from the last stigmata before breaking up into a great number of fine tracheal tubes. These tubes are carried back into two main bundles, one joining its fellow of the other side and supplying the ventral organs and the legs, the other, or dorsal bundle, curving widely round in a semicircle and enclosing with its fellow a translucent area clearly visible during life (*cf.* the same appearance in *Cheyletus eruditus*). The tracheæ do not branch or anastomose and each terminates in a marked dilatation (*cf. Cheyletus*).

The Gut.—So far as can be seen in whole preparations the gut consists of a central ventriculus from which are given off a pair of anterior cæca which are lateral to the translucent area mentioned above, and also a pair of posterior cæca which meet but do not coalesce at the posterior margin. There is probably no anus.

The Female Genital Organs.—The ovary may be seen in stained preparations as a compact mass of eggs lying ventrally about the middle of the body. The orifice shown in Fig. 21 between the hindmost pair of ventral hairs (it has the appearance of a transverse fold) is probably that by which the male spermatic products are received.

The Male.

The male (Fig. 22) of this species like that of other Tarsonemids is heteromorphic.

Size.—0·17 mm. long.

Colour.—Pale yellowish as in the female.

Shape.—More roundly oval than the female, but tapering from the third pair of legs to the posterior margin and much flattened dorsoventrally. As in the female the shape in the mounted preparations and consequently in the figures is not the same as in life.

Dorsal Aspect.—The cephalo-thoracic suture is situated between the second and third pair of legs, but nearer the former; there are traces of three other segmental sutures posterior to this. The dorsal chætotaxy is as follows: one pair of long single hairs behind the line of insertion of the first pair of legs; another pair about the level of the insertion of the second legs but nearer the margin; a third pair just behind the cephalo-thoracic fold; a fourth pair at the level of the insertion of the fourth leg; a lateral outstanding marginal hair behind the cephalothoracic suture; a long pair on the posterior margin.

Ventral Aspect (Fig. 22).—The mouth parts are in camerostome as in the female but are still more rudimentary. The sternum is joined by the first and second pair of epimera and bifurcates to form the collar; the remaining epimera are free.

The Legs.—The first two pairs are widely separated from the last two pairs; all are composed of five segments.* The first pair are short and stumpy and in some specimens are distinctly geniculate; the first three segments are much broader than long, the tarsus is not so incrassate and the hook is more minute than in the female, the hairs and spines being the same, there are, however, no lateral chitinous plates. The second pair are not so robust as the first; the tarsus bears a large cup-shaped membranous sucker. In the third pair of legs the first segment is much the largest. The fourth pair like the third except that they are comparatively short. The tarsi of both bear cup-shaped suckers.

No trace of a respiratory system has been seen in the male, but the gut and dorsal excretory vessel are as in the female. The genital aperture is large, sub-circular, and widely open, with a chitinised brim or lip; it is situated on the ventral surface of the posterior tapering part of the body. Both it and the genital armature are shown in

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* In many preparations it is difficult to define more than four segments clearly in the first leg, this is probably due to one of the proximal ones becoming telescoped in the preparations.

Fig. 22. About the centre of the orifice are two pairs of minute suckers and there is another pair of suckers just within the posterior margin near to the two long posterior marginal hairs.

Systematic Position.

There can be no doubt that this acarid belongs to the family Tarsonemidae and that the following characters taken in conjunction are sufficient to justify inclusion, viz.: the traces of abdominal segmentation; the minute trophi; the presence of tracheae and the position of the stigmata; the single recurved claw on the first leg of the female; the sexual dimorphism. The broad facts of the life-history such as the viviparous habit, accompanied by distension of the abdomen and the parasitic life are so similar to those of *Pediculoides ventricosus* and of other members of that genus and at the same time so unusual among the acarina that a relationship to this genus is probably indicated. Moreover, the shortened fourth leg and the large genital orifice of the male, and the long terminal bristles of the fourth leg of the female accompanied by a sucker are also found in *Pediculoides ventricosus.* The unpaired median excretory organ and the blind alimentary canal found in this species as well as in *Pediculoides* constitute another resemblance. There are two points in which this species differs from other Tarsonemids; the female is without the pseudo-stigmatic organ generally looked upon by authors as characteristic of the females of the family (Berlese 86, Canestrini 88, p. 309, Brucker 01); the two curved claws which appear to be universally present on the second and third legs accompanied by a sucker are absent from both male and female. In connection with the first of these points it may, however, be noted that G. Paoli (11) in his monograph on the Tarsonemidæ published in 1911, figures several species without the organ in question, but makes no mention of the absence or omission in the text, and that *Amerling (68) mentions a vegetable feeding form related to *Pediculoides* without the organ and names it *Therismoptes.* With regard to the second point of difference Banks (13) says in his definition of the family that the tarsi of all the legs but the first *usually* have a sucker and two claws, but he does not mention or figure any that are without.

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* We have been unable to consult this paper ourselves, but it is discussed rather fully by Brucker (01), p. 392.

PART II.—ECONOMIC AND EXPERIMENTAL.

ACARIDS IN STORED GRAIN.

Field of Observation.—This has been confined to imported wheat which of course has formed the greater part of the grain used in the country. We have, through the courtesy of the Liverpool Grain Storage & Transit Company, been enabled to observe the conditions under which wheat is stored in bulk during the course of the 16 months (March, 1917, to June, 1918). The dock-side silos belonging to this firm are the largest in the United Kingdom and afforded therefore a specially favourable base of observations. We have also been in touch with some of the smaller grain storage concerns, in whose granaries the wheat is stored upon floors. As between the merits of floor and silo storage we shall not attempt to discriminate, both have advantages and disadvantages. Undoubtedly where enormous bulk of wheat has to be dealt with the ready and rapid manipulation obtained in silo storage outbalances any disadvantage, minimising for example the fact that the condition of the wheat in every part of the mass is not readily gauged. For relatively small concerns floor storage has obvious advantages, the grain is easily observed and its condition watched and it can be kept well ventilated and cool ; on the other hand it requires a good deal of man-handling. As *Aleurobius farinae* is far the most serious of the acarid pests all the following remarks apply to it.

Kinds of Wheat Affected by Acarids.

The kinds of wheat most liable to serious infestation are the various grades of Manitoba, of which no one grade seems to be more specially liable than another. Instances of Montana, Philadelphian Spring, Northern Spring and Western Wheat have come to our notice, but they are in comparison relatively infrequent. No single instance of infestation of wheat from hot regions has been brought to our notice.

The Influence of the Seasons.

It has become apparent during the past year that while mites may be found in wheat at all seasons, it is during the warm summer and autumn months that they are most plentiful and most likely to occur in detrimental numbers ; this has also been the experience of the granary staff over a long period of years. Undoubtedly the summer temperature is the chief reason for this increase, but in the case of stored grain a second factor must be taken into account. In summer and autumn the stocks, harvested the previous autumn, have lain in bulk during transit and storage, and time enough has elapsed to allow any deteriorative processes due either to original inferiority or to bad conditions of transit and storage to spread throughout the parcel and become manifest. Chief among these deteriorative processes must be reckoned those due to bacterial activities or to enzymes intrinsic to the wheat itself, which bring in their train a large increase of moisture content and a rise of temperature. These processes if allowed to proceed unchecked may lead to intense " sweating " of the stock with a great rise of temperature (sometimes as high as 120° F.) and to ultimate rotting and putrefaction. It is at the commencement of this process, when the wheat is beginning to go " off " that mites generally occur in large quantities. We think it is improbable that they are the cause of the evil, but when present in large numbers they undoubtedly accelerate the deterioration.

Methods of Moisture Estimation.

The determinations of moisture percentages of wheat quoted in this paper have been made by drying *whole* grains in a steam oven for 20 hours. Most mills and granaries have their own methods of moisture determination and any figures they make use of are necessarily relative and empirical. It may be noted, however, that an addition of 1 per cent. to our figures will give the percentage that is obtained when the wheat is ground in a small hand mill before drying in the oven for the same period of time.

In another more speedy method developed by the United States Bureau of Agriculture (Duvel, 10) the wheat is placed in a fractionating flask containing light engine oil and raised to a temperature of 180° C. in the course of 20 minutes, the water distilled over in this period being read off as a percentage amount of uncombined moisture present in the wheat. This apparatus is largely employed in America and by some firms in this country; we employed this method at the beginning of our investigations, but subsequently abandoned it.

Distribution in Large Parcels of Wheat.—With a view to ascertaining the distribution of mites throughout the bulk of an infested stock, samples were taken continuously from the band at intervals of 10 minutes during the transference of a parcel of " mitey " wheat from one silo to another.

The following are the particulars :—

Wheat—No. 2, Manitoba.
Received into store July 10, 1917, and not disturbed until
Date of observation—October 3, 1917.
Amount—92 tons.
Time taken in running—1 hour 20 mins.
Dimensions of silo—12 × 12 × 40 feet (about).

This wheat, until September 1, was normal as to condition and temperature. After that a slightly increasing rise of temperature was registered until 68° F. was reached, 8° above the temperature of the floor, and the wheat was reported "mitey." Samples taken every 10 minutes during the whole of the run showed on the whole a fairly equal distribution of mites, and the mitey smell was noticeable throughout. The mites, however, were decidedly more numerous in the wheat which left the silo at the very end. This portion of the wheat, the dregs of the silo, was also very dusty. It is probable from the form of the silo, and the fact that the valve was situated in the centre of the bottom that it was evacuated from above downwards. Moisture determinations were made in the laboratory from samples taken at the commencement, middle, and end of the run and were respectively 12·4 per cent., 13·5 per cent., 13·8 per cent.

In floor storage at a depth of 6 to 8 feet the same even distribution of the mites occurs, though they tend sometimes to congregate at various points on the surface, a process which appears to lead to the death of those that do so.

Methods of Detection.—The presence of mites in any quantity in grain may always be detected by the associated unpleasant and peculiar smell, known to the trade as "minty" or "mitey"; when in very large quantities they may cause the grain to appear literally heaving; in less obvious quantities it is best to riddle some of the wheat in which mites are suspected and to examine the riddlings with a hand lens.

Conditions of Existence.—The connection between moisture content and the presence of mites in grain has probably been suspected by the trade, if only in a vague way. It was obviously of capital importance in any exact investigation to discover the precise effect of this factor on the presence and increase of the mites. Careful moisture determinations were accordingly made of all stocks that were reported "mitey" and it was found that no case of serious mite infestation occurred in which the percentage of moisture was below 13 per cent., while the usual figure for badly infested stocks was somewhere between 14 and 18 per cent. This result from the granaries received confirmation from laboratory experiments. Jars containing about 6 lb. of No. 1 Manitoba wheat in good condition but with varied moisture content were infected with small quantities of *Aleurobius farinae* and kept at a temperature between 50° and 60° F. In two of the jars where the moisture content was 9·4 and 12·9 per cent. respectively, the introduced mites died in a day or two. In another jar in which the moisture percentage was 13·4 per cent. they lived and increased, but not very rapidly, but in other jars in which the moisture content was 14, 15·5, 15·8 and 16 per cent. the increase was very rapid indeed, so that at the end of a month the mites were swarming and the wheat had a strong mitey smell. From these results it is reasonable to infer that the lower limit of moisture for mites is somewhere near 13 per cent. in grain. It may be added in this connection that apart from these definite experiments very numerous moisture determinations have been taken of all substances used for experimental purposes and these bear out the above results in every way.

Wheat of varying moisture content for the last experiment was obtained by exposing a thin layer of the grain with an initial moisture content of 9·4 per cent. to a saturated atmosphere for different periods of time.

Temperature.—All observations point to temperatures between 65° to 75° F. as the most favourable for rapid increase of mites given the essential moisture conditions. In the granaries, as stated above, mites are most liable to appear in numbers when the wheat is beginning to go "off"; when the heating process reaches 80° F. few mites as a rule are found. It must be noted, however, that on one occasion we found large numbers of mites in an apparently flourishing condition in a parcel of badly heated and sweating wheat of which the temperature was 115° F.

The following experiment was arranged in order to study the effect of temperature on increase of the mites: four jars containing each about 1 lb. of No. 1 Manitoba wheat carefully sifted with a moisture content of 17·9 per cent. were infected with a few *Aleurobius farinae.* Two of these were allowed to remain for seven weeks, at a temperature ranging between 72° and 62° F., but only occasionally below 65° F. Accompanying these two jars was a similar one as a control containing wheat from the same sample, but free from mites. The two other infected jars also accompanied by an uninfected control jar, were at the same time kept at a temperature between 57° and 63° F. At the end of the period it was found that increase of the mites had occurred in the jars stored in both places, but the infestation in the wheat kept at the lower range of temperature was about one-third that of the wheat kept at the higher range. The grain in all the jars (including the controls) had, during the course of the experiment, lost moisture to the varying extent of 1 to 3 per cent.

Sources of Infestation.—How and where wheat becomes infected with acarids is not yet satisfactorily determined. When their wide geographical range is considered the probability is that most stocks from temperate countries contain them in small numbers, and that their chance of developing into a pest depends as we have seen, upon other conditions, especially upon moisture.

The Nature of Injury.—A great deal of uncertainty has prevailed heretofore with regard to the precise nature of the injury to grain resulting from mite infestation, and the fact that in former years the presence of mites was regarded as a guarantee of quality by millers is sufficient evidence of this. The objectionable smell which is associated with their presence in quantity must certainly be reckoned as detrimental. The granary staff also attribute to their activities the formation of a large amount of dust and dirt which hinders free ventilation between the grains and so tends to promote the sweating evil. Apart altogether from these secondary effects of their presence, the fact that *Aleurobius* actually devours the endosperm in the manner shown above (p. 9) has to be reckoned with ; it must considerably impoverish the wheat. The extent of such damage would, of course, be even more difficult to assess than that due to the ravages of weevils, and in our opinion cannot at the present time be usefully quoted.

It is possible to derive figures showing weight loss due presumably to the ravages of mites from small laboratory experiments, but these cannot be safely applied to bulk. On the other hand an examination of the books at the granary showing the "in and out" weighings of large parcels of wheat has convinced us that it would be difficult or impossible with the methods in use there to assign any deficit which may appear against an infested stock to the agency of the mites alone.

Prevention and Remedies.—The results of the investigation show that wheat whose moisture content is below 13 per cent. is immune to injury from mites even when exposed to the risk of considerable infestation. Security from this pest may therefore be insured by passing the wheat into store with a low moisture content and in a clean condition ; by adopting this plan the risk of subsequent heating would also be greatly reduced. To store no wheat which it is intended to keep for any considerable period of time whose moisture content is above 11 per cent. is no doubt a counsel of perfection and could not be realised at the present time, but its importance cannot be too strongly emphasised should the creation of a grain reserve be undertaken at some future date, and adequate cleaning and drying machinery should be provided in all large granaries which are constructed in the future.

The condition of parcels of wheat which have become badly mite-infested can be much improved, and further damage prevented, by subjecting them to some process which will dry the grain and at the same time kill off most of the mites and remove their bodies, such as a blast of hot air followed by cooling. Wheat in bulk can be so treated in such a machine as the "Hess Drier and Cooler." In this apparatus the grain to be treated is passed from a band conveyor into a garner, whence it is allowed to fall by gravity into a chamber containing a series of horizontal racks or baffle-plates arranged in a zig-zag manner one above the other. This secures the disposal of the grain in thin columns and also thorough mixing and aeration. It is in this chamber, if so desired, that the wheat comes into contact with a draught of hot air. After a period which is varied in accordance with the condition of the wheat to be dried, it is allowed to pass into a second precisely similar chamber beneath, where it is subjected to a draught of cold air and cooled ; it then passes into a hopper beneath which discharges on to a band conveyor.

Cold air is drawn through the lower chamber by a powerful fan and the same current passes through the fan and is forced on over a series of steam coils, from thence it goes through the wheat in the upper chamber. This system of air circulation is economical, as the heat given off by the cooling grain beneath is utilised in the drying process above.

The following particulars of a parcel of wheat passed through the machine will show the results of the treatment :—

Wheat, No. 1 Manitoba :—

(i) Received this country March, 1917.
(ii) Reported warm and "mitey" during September.
(iii) Passed through Hess Drier, September 19, 1917, and then
(iv) In contact with a temperature of 140° F. for ten minutes.
(v) Loss of weight during operation = 1·32 per cent.
(vi) Moisture before drying = 15·2 per cent.
(vii) Moisture after drying = 13·8 per cent.

The mitey smell quite disappeared after treatment and an examination of a 3 lb. sample from bulk showed very few mites (about five or six). (Before treatment a similar sample showed very great numbers of mites.) The dust blown out of the wheat and lying round the machine was found to consist largely of the dead bodies of acarids. The wheat was kept in store for some months after this and no further trouble was reported. About 5 tons an hour can be treated in this way, and the average cost is from 1*s.* to 1*s.* 6*d.* a ton (September, 1917). The machine is worked by one attendant.

A parcel of Government oats examined before and after treatment in the machine showed the same great diminution in the number of acarids and loss of mitey smell. Costly and dangerous fumigation methods are therefore not necessary as a remedy for acarids.

ACARIDS IN FLOUR.

Aleurobius farinae is the only acarid we have found in flour. This substance undoubtedly suffers much deterioration from mites and in it under favourable conditions their rate of increase is nothing short of extraordinary. Although millers and bakers with whom we have been in touch have not complained during the past year of much trouble from mites, we have found many samples which contain them and they are certainly often unsuspected dwellers in household flour bins. Mites may be detected in flour by smoothing out the surface with some polished substance such as glass or a metal spatula and then carefully observing it after the lapse of a few minutes. If the creatures are present their movements will cause the appearance of small hillocks on the freshly smoothed surface, and from the number of these hillocks some idea of the degree of infestation may be inferred.

Nature of Injury.

Flour which is heavily mite-infested is certainly ruined. It has a most unpleasant odour and becomes much discoloured owing to the quantities of excrement with which it is charged (Fig. 28). As a result of the infestation the moisture content increases and in the later stages moulds are found. The appearance of mite-infested flour as seen against the surface of a glass containing vessel is seen in Fig. 29 (Pl. XI.).

Conditions of Existence.

Moisture.—In flour as in wheat moisture content is of primary importance in connection with acarids. An experiment similar to that carried out in the case of wheat demonstrated that in jars in which the moisture content of the flour was below 11·5 per cent. any mites introduced died very soon, while in those in which the moisture was respectively 12·5, 13·6 and 14 per cent. they increased rapidly.

It might at first be thought that the necessity to *Aleurobius* for a certain minimum moisture content in its foodstuff might be due to the inability of the jaws to penetrate the bran coats of the wheat berry unless these were softened, and the fact that a lower moisture percentage tolerated when living in flour seemed to confirm this. We have since come to the conclusion that moist surroundings are necessary for respiratory purposes. In the Tyroglyphidae this function takes place through the skin, there being no tracheae or other special respiratory organs. It is well known that gaseous exchange cannot take place through a membrane unless that membrane be moist enough to allow the gases to pass through in solution. It therefore follows that if the skin of *Aleurobius* becomes dry the animal will be unable to respire and death will result. A small experiment confirmed this hypothesis. A number of healthy *Aleurobius* were confined in two breeding cells without food. One cell was kept in a box containing the ordinary atmosphere of the laboratory, the other in a similar box in which the atmosphere was kept moist. The mites in the first box were all dead after ten hours, while those in the second lived for three or four days and even laid eggs.

Temperature.—Under the same initial conditions of moisture temperature is undoubtedly a great factor ; below 55° F. the increase is slow while between 65° and 70° F. it is very rapid.

A parallel experiment to demonstrate the influence of temperature on the rate of increase of mites was carried out under the same conditions as to time and method as that described above for wheat (p. 28). About 1 lb. of State flour with an initial moisture content of 15·6 per cent. was placed in each of six jars, four of which were infected with a small number of *Aleurobius farinae*, and two were left uninfected as controls. Two infected jars and a control were kept at a temperature ranging between 72° and 62° F. on the one hand and 57° and 63° F. on the other. After seven weeks it was found that, as in the case of the wheat, the mites had increased in all the infected jars, but the disparity between the rate of increase in the jars kept at the two ranges of temperature was much greater, being very much more rapid at the higher temperature. At both ranges the control jars had lost moisture to the extent of about 1 per cent., and while the infected jars at the higher temperature had gained about 3 per cent. of moisture, in those at the lower there was neither gain nor loss in this respect.

The Effect of Hermetical Sealing.

Professor Dendy, F.R.S., working on weevils found that hermetical sealing is rapidly fatal to them (Dendy 18). We therefore tried the effect of this treatment on acarids in flour in the following experiment. Some flour of moisture content 14·9 per cent. and heavily infested with acarids was placed in jars :—

Jar I was three-quarters full ; jar II was three-quarters full ; jar III was half-full ; jar IV was one quarter full.

After three or four days during which the mites were seen to be flourishing in all the jars, jars II, III and IV were sealed hermetically, while jar I was left as a control. In two days all movement of the mites had ceased in jars II and III, and was very sluggish in jar IV. In three days the mites were dead in jars II and III, and in IV movements were almost imperceptible. In four days the mites were also dead in jar IV. In jar I the mites were flourishing. All except the eggs had apparently died of asphyxiation in the three sealed jars. After the lapse of a week jar II was unsealed (care being taken to avoid re-infection) and after a month jar III also. In a few days in both cases a few borings and workings were visible, showing probably that some of the eggs at any rate had not succumbed to the treatment but that development had been prohibited by the lack of ventilation, and was resumed when fresh air was once more admitted.

Effect of Desiccation on the Vitality of the Eggs.

Some flour heavily mite-infested and of moisture content 14·6 per cent. was dried down to 4 per cent. in an incubator at 35° C., and also in a desiccator at laboratory temperature to 10·7 per cent. After six days both samples were examined microscopically, and no sign of life could be seen in either. A small quantity of each was then placed in a jar in which the atmosphere was kept moist by appropriate means, due precautions being taken to avoid the introduction of mites from outside.

After four days signs of the presence of living mites were visible in both jars, showing that some at least of the eggs had resisted the desiccation.

After the lapse of one month some more of both samples of the dried flour (which had been kept dry all this time) was placed in two similar jars in which the atmosphere was moist. In a month no signs of life had appeared in either, showing that the eggs are unable to resist prolonged desiccation, or to revive after, even when conditions become once more favourable.

Thus it would appear that desiccation is more effective in destroying the eggs than hermetical sealing.

Prevention and Remedies.

Prevention from attack may be secured by storing the flour with a low moisture content, *i.e.*, below 11 per cent. Remedies when the flour is already infested are obviously difficult to apply. Probably, if not applied too late, heat is the best remedy; and small quantities could be saved from further damage by heating throughout for an hour or more at 150° F. In response to the inquiries of a miller we carried out some experiments on the lethal effect of various temperatures on acarids in flour. He pointed out that in mills if the result was equally effective, a lower temperature applied for a longer period would be preferable to a higher temperature for a short period owing to the large amount of machinery which might be injured in the latter case. We found that the lowest absolutely lethal temperature was 120° F., and that this must be applied for at least twelve hours to be effective. Lower temperatures than this although they greatly reduced the mites did not ensure the destruction of all the eggs and, as a consequence, mites reappeared in the jars after the lapse of some time.

Sifting the affected flour through very fine bolting-silk sieves has been suggested and would doubtless remove most of the mites, but the mesh would have to be very fine to prevent the passing of the eggs which measure only 0·12 by 0·08 mm.

ACARIDS IN OTHER CEREAL PRODUCTS.

Aleurobius farinae frequently infests bran, rolled oats and oatmeal, the conditions of its existence in these substances is the same as in flour and the nature of the damage is also similar. One case of infestation of rice has been sent us. It is a fact of some interest that *Aleurobius farinae* has been found on British Army horses in France and sent here for identification. These were no doubt migrants from the fodder and in no sense parasites, but their resemblance to the allied Sarcoptids which cause Acariasis has in many cases led to the needless isolation of numbers of horses.

CONCLUSIONS.

1. Wheat and flour are liable to attacks and injury by acarids.
2. *Aleurobius farinae* is the acarid responsible for most of the damage.
3. Mites will not injure wheat and flour in which the moisture is 11 per cent. and under, whatever the temperature may be. They may flourish and increase exceedingly when the moisture is over 13 per cent.
4. Given favourable (to them) moisture conditions increase is very rapid at temperatures between 60° and 75°, less so between 50° and 60°, while between 40° and 50° F. increase is slow.
5. The remedy for mite-infested wheat is to screen it thoroughly, in order to remove as many of the mites as possible, and subject it to some treatment whereby the excessive moisture is reduced, such as a blast of hot air followed by cooling.
6. The injury to flour is much more serious and much less readily combated than in wheat. Flour which is heavily mite-infested is unfit for human consumption (*see* Prof. Beattie's Report, Appendix I).

This research has been carried on in the Zoological Laboratory of the University of Liverpool in a room placed at our disposal by Prof. Herdman.

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EXPLANATION OF REFERENCE LETTERS ON PLATES.

a.gl.	accessory gland.
a.s.	anterior stigma.
b.b.	bifid bristle.
bs.	"bruststiel."
co.	chitinous collar.
cœ I, II, III	cæca of mid-gut.
cx.	coxa.
d.s.	dorsal stigma.
d.-v.m.	dorso-ventral muscle.
exc.	excretory vessel.
fe.	femur.
h.h.	sensory hairs.
i.m.	"inner mass" of ovary.
L. III, IV	Leg. III, Leg. IV.
l.e.	lateral extension of "collar."
lu.	lumen of ovary.
md.	mandible.
m.exc.	muscle of excretory vessel.
m.ph.	muscle of pharynx.
m.s.	median stigma.
n.s.	brain.
oe.	œsophagus.
o.m.	outer wall of ovary.
ovd.	oviduct.
ph.	pharynx.
p.s.	posterior stigma.
pt.	patella.
r.s.	rostral stigma.
s.agl.	secretion of accessory gland.
s.b.	"supporting" bristle.
s.gl.	salivary gland.
s.r.	sense rod.
ta.	tarsus.
tch.	trochanter.
tib.	tibia.
tr.	trachea.
t.t.	tracheal trunk.
va.	vagina.
v.a.o.	vulvo-anal orifice.
x.	spherical chitinous body.

EXPLANATION OF PLATES.

TEXT FIGURE (p. 6).—*Aleurobius farinae.*

(*a*) First leg (right) of the male from dorsal aspect. × 330.
(*b*) Mandible of male. × 330.

PLATE I.

Aleurobius farinae.

Fig.
1.—Larva. Dorsal aspect. × 330.
2.—Larva. Ventral aspect. × 330.

PLATE II.

Cheyletus eruditus.

Fig.
3.—Larva. Dorsal aspect. × 260.
4.—Female from the dorsal aspect showing cæca of mid-gut and excretory vessel. × 80.

PLATE III.

Cheyletus eruditus. Adult female.

Fig.
5.—Tarsus of Leg III, ventral aspect. (*s.b.*) "Supporting" bristle; (*h.h.*) sensory hair; (*b.b.*) bifid bristle. × 430.
6.—Tarsus of Leg III, side aspect, "Offsets," bifid bristle and ambulacral sucker. (*tr.*) Tracheal tube. × 430.
7.—Tarsus of Leg I, ventral aspect. (*s.r.*) Sense rod. × 430.
8.—Pedipalp of adult, dorsal aspect. × 330.
9.—Pedipalp of adult, ventral aspect. × 330.

PLATE IV.

Cheyletus eruditus.

Fig.

10.—Respiratory system in the capitulum of the adult, from the dorsal aspect. Here the three pairs of stigmata are shown (*a.s.*, *m.s.*, *p.s.*) connected by the jointed chitinous " collar " (*co.*) and its lateral extensions (*l.e.*). The two main tracheal trunks (*t.t.*) are seen leading back from the median dorsal pair of stigmata and breaking up into numbers of fine tracheal tubes after leaving the capitulum. The three fine tubes (*tr.*) leading from the lateral marginal stigmata (*l.s.*) are also figured. × 330.

11.—Cloacal aperture of larva, showing so-called " anal " papilla. × 660.

12.—Cloacal aperture of deutonymph, showing so-called " anal " papilla. ×660.

13.—" Vulvo-anal " orifice of female, showing " anal " papilla and bristles. (*x.*) Spherical chitinous body seen through the cuticle. × 330.

PLATE V.

Cheyletus eruditus.

Fig.

14.—Transverse section at the level of attachment of the third legs, L. III. The ovary with ova at various stages is seen to consist of an inner mass (*i.m.*) surrounded by an outer wall (*o.m.*). Dorsally the inner mass and outer wall are continuous, but are separated beneath and at the sides by a narrow lumen (*lu.*). The cavity (*cœ.*) of the mid-gut and its lateral cæca are shown diagramatically between the ovary and the excretory vessel (*exc.*). Muscles are shown by cross hatching. × 200.

15.—Transverse section, slightly posterior to the insertion of the fourth leg (L. IV). Yolk-laden ova are seen in the two oviducts (*ovd.*) which are here shown joining to form the median vagina (*va.*), which is occupied by a single large ovum. The hind pair of cæca (*cœ.* III) are seen on either side of the accessory gland (*a.gl.*) and the excretory vessel (*exc.*). The cells of the excretory vessel are collapsed and the lumen contains the characteristic excretory crystals. × 200.

16.—Transverse section of hind region of body, showing the excretory vessel (*exc.*) extending ventrally between the hindmost cœca (*cœ* III) before opening into the cloaca. The inturned lips of the " vulvo-anal " orifice (*v.a.o.*) are also seen. × 200.

PLATE VI.

Cheyletus eruditus.

Fig.
17.—Transverse section of pharyngeal region. The heavily chitinised pharynx (*ph.*) with its accompanying bundles of dilator muscles (*m.ph.*). Above is the salivary gland (*s.gl.*). On either side are two slips of dorso-ventral muscle (*d.v.m.*) in which cross striation and Dobie's line are well shown. Above the gland are the muscles (*m.exc.*) attaching the excretory vessels to the rostrum. × 200.
18.—Transverse section of the brain, showing central medullary region surrounded by the nucleated cortical layers. × 330.
19.—Squamous cells of the epidermis. × 200.
20.—Longitudinal section, nearly, but not quite, sagittal. It shows the compact arrangement of the genital organs. The position of the œsophagus in the brain (*n.s.*) is shown by a broken line (*oe.*). × 200.

PLATE VII.

Acarophenax tribolii, sp. nov.

Fig.
21.—Young female. Ventral aspect. × 330.
22.—Male. Ventral aspect. × 330.

PLATE VIII.

Acarophenax tribolii, sp. nov.

Fig.
23.—Young female. Dorsal aspect. × 260.
24.—Distended female. Dorsal aspect. × 200.
25.—Distended female. Latero-ventral aspect. × 200.
26.—Respiratory system of young female, dorsal aspect. (*r.s.*) Rostral stigmata. (*d.s.*) Dorsal stigmata. The fine tracheæ supplying the ventral parts are shown in thinner outline. Note the dilated terminations of all the tracheæ. × 330.

PLATE IX.

Fig. 27.—*No. 1, Northern Manitoba Wheat.*

1st row—Sound grains.

2nd and 3rd rows—Grains injured by *Aleurobius farinae.* The two central grains of each row are split longitudinally to show how they have been hollowed out by the work of the mites. In three of the others the small entrance hole bored in the embryonic region of the grain is shown. × 6.

PLATE X.

Fig. 28.—Microphotograph from a preparation in clove oil of State Flour which was heavily mite-infested. (*a*) acarid ; (*b*) egg of acarid : (*c*) fæcal pellets. × 100.

PLATE XI.

Fig. 29.—Photograph of burrows or workings produced by acarids in an infested sample of State Flour as seen against the surface of the glass containing vessel. × 10.

APPENDIX I.

PRELIMINARY NOTE ON SAMPLES OF FLOUR SUBMITTED FOR BACTERIOLOGICAL EXAMINATION BY PROF. NEWSTEAD, F.R.S.

By J. M. BEATTIE, M.A., M.D., Professor of Bacteriology in the University of Liverpool.

Sample I.—Marked—"Sample from R.S." This was dark brown in colour, especially in the deeper parts of the vessel in which it was contained, and very moist (also semi-liquid). It had a mouldy smell.

Sample II.—Marked—"State flour, infected." This was very dark in colour and moist, and formed into a definite cake. It had a smell of butyric acid.

Sample III.—Marked—"Self-raising flour (War) infected." This was also moist and dark brown in colour, with a distinct ammoniacal odour.

Various moulds (white and brown) were obtained principally from Sample I. These of themselves did not produce the characteristic degeneration seen in the original samples and were therefore not dealt with further.

A number of bacteria were isolated, but not more than three types seemed to be concerned in the process :—

1. A coccus, presenting the microscopical characters of Staphylococcus and producing a rich orange-yellow colour on the media used; up to the present it would appear to be *Staphylococcus aureus*, but I am not satisfied that it is really this organism—its colour seems to be retained very tenaciously, and in any moist media this yellow colour becomes very apparent. This organism, probably, has some effect in producing the brownish colour seen in the degenerated flour.

2. *Ba.*—A large bacillus forming spores very rapidly, and both in microscopical and cultural characters resembling the *B. mesentericus* group. It is very markedly aerobic.

3. *Bβ*.—A bacillus—gram negative in staining reaction—varying in length—usually, however, short with longer filaments. It grows best at room temperature—at first, as isolated colonies, very viscid in character, and, therefore, tending to be "heaped up." Later, it becomes slightly adherent to the surface of solid media such as agar, and is so tenacious that it strips off like a definite membrane. It is very hard to break up, and can be pulled into long viscid (mucus-like) strings. I have compared this organism with *B. viscosus* (of ropy bread), and it certainly is distinct from it. All these organisms grow well on all the ordinary laboratory media.

The principal organism concerned in the degeneration of the flour is Bβ, and I have been able to reproduce in the test tube—working with sterilised flour, and this bacillus alone—the appearance seen in the original sample—the dark semi-liquid mass. The change is first seen at the bottom of the tube, but gradually spreads upwards, invading the whole mass, provided there is sufficiency of moisture. In the absence of a sufficient degree of moisture (I have not so far estimated the amount of moisture required) the organism does not flourish. The organism flourishes, both aerobically and anaerobically, and its growth at the bottom of the tube may have some relation to its anaerobic growth. This view gains some support from the fact that a more rapid degeneration of the flour takes place if Bα—a very strict aerobic—is associated with Bβ. On the whole, however, I am inclined to view the more rapid growth at the bottom of the tube as due to the superficial drying, and the greater moisture at the bottom.

In regard to the (?) butyric acid odour, this is always apparent, and the ammoniacal odour is also appreciable to the senses in the primary cultures from the flour, but in subsequent sub-cultures it is not detected. If, however, litmus paper is exposed over the surface of the plates containing cultures of Bα and β, an alkaline reaction is obtained in a few minutes This is more markedly the case with Bα than with Bβ. The very obvious ammoniacal odour in the original degenerated flour of Sample III, may have been due to chemical changes in the alkalies added to the "Self-raising" flour, or to the greater amount of excreta of the Acarids with which it was infected. The presence of the excreta would also account for the more pronounced ammoniacal odour in the primary cultures (the excreta being taken on the plate in primary inoculation), than on the subsequent sub-cultures.

As regards the source of the bacteria, I have examined various samples of flour, and have not found in any of them either the coccus described above or Bβ, and I would suggest as the possible source of these the excreta of the Acarids. I hope later, in collaboration with Professor Newstead, to investigate the question. The present work seems to be conclusive that the degeneration is produced by bacteria, and that, if the flour is properly stored and kept dry, this degeneration will not take place.

APPENDIX II.

Report on Six Samples of Flour into which Mites have been Introduced.

By A. E. HUMPHRIES, Member of the Royal Commission on Wheat Supplies.

In the autumn of 1917, I had examined and tested a sample of flour very badly infested with mites, and had found that apart from the presence of the mites, it was quite unfit for bread-making purposes. I had sifted it through silk sieves of increasing fineness, and had found that the mites were extracted from the flour by sifting it through a No. 14 silk. Such silk has about 140 meshes per lineal inch, that is to say, about 19,600 meshes per square inch. It may be desirable to point out that the size of the open space of each mesh is very much less than $\frac{1}{19600}$ of a square inch. Such sifting removed a large proportion of the bulk, for the flour in question contained a large proportion of particles of relatively large size. I had found that the entire flour and its finer mite-free particles yielded little or no gluten, but in various respects the flour was abnormal, and it was unsafe to deduce from the tests made, anything as to the effects produced by mites. With this information in our possession, Prof. Herdman, Prof. Newstead, and I, decided to make a set of tests on the following lines. I manufactured these six flours :—

A. Pure wheaten flour representing an extraction of about 72 per cent.
B. Pure wheaten flour representing an extraction of about 80 per cent.
C. Pure wheaten flour representing an extraction of about 90 per cent.
D. A mixture of 80 per cent. B. flour and 20 per cent. barley flour.
E. A mixture of 80 per cent. B. flour and 20 per cent. maize flour.
F. A mixture of 80 per cent. B. flour and 20 per cent. rice flour.

For these trials the wheats used were a mixture of home grown and imported kinds, which my firm was at the time using for commercial purposes. The barley used was home grown, of fair quality, 1917 crop. This grain originally contained a high percentage of natural moisture, and was to some extent sprouted. The maize flour was made from No. 3 American Mixed Maize.

It seemed to me undesirable to take any special precautions in the packing and storage of these flours, so they were placed in bags made of jute cloth of a weight and quality commonly used by millers for the storage and delivery of flour. Some of each flour so packed was sent to Liverpool in December, 1917, and the remainder was kept at Weybridge. In December, 1917, I made certain tests, to be referred to hereinafter, and it was arranged that Prof. Newstead should introduce mites into the sample lots of flour sent to him, and that he should after a lapse of time return the infected flour to me. This arrangement was made in the expectation that the flour kept at Weybridge would remain free from mites, and that the tests I made in December, 1917, could be repeated on the mite-free and mite-infested flours, each originally identically the same in all respects. But this plan could not be carried out, for in June, 1918, when the flours sent to Liverpool were returned to me, I found that the counterparts kept at Weybridge had also become infested with mites. The original plan of experimental work had, therefore, to be changed. If, apart from effects produced by mites, the flours had degenerated in essential particulars, the enforced modification of the plan might have been unfortunate, but under the existing conditions the mishap has entailed no important consequences.

I had originally made precise records on essential points, so comparison can be made between those records made in December, 1917, and those made in July, 1918, on the six samples which had been sent to Liverpool.

Water Content.

For commercial purposes, I use a well-ventilated oven, with ample air space, heated electrically, and the temperature is automatically, by means of a mechanical device, maintained within one degree either way of 100° C. This method on such flours gives a reading about 1·3 per cent. in excess of that obtained from the same flours by the use of a water oven, with an exposure of three hours in each oven. As my figures are comparative, I need not, with greater precision, convert them to a water oven basis. The comparison is as follows :—

	December, 1917.	July, 1918.
Sample A.	14·33	13·49
,, B.	14·30	13·60
,, C.	14·15	13·21
,, D.	13·71	14·93
,, E.	14·03	13·50
,, F.	13·84	13·35

Acidity.

Stated as H_2SO_4 the figures for relative acidities are as follows :—

	December, 1917.	July, 1918.
Sample A.	·127	·098
„ B.	·108	·127
„ C.	·118	·152
„ D.	127	·294
„ E.	——	·127
„ F.	·108	·118

Nitrogen and Gluten.

When I am dealing with pure wheaten flours, I usually estimate the gluten figures by two methods—(*a*) by severe washing, (*b*) by estimating the Nitrogen content and multiplying that by 5·68. I have recently tested six flours for the Indian Government. From the best of the six, the figures by both methods were substantially the same; from the other five, the figures by the (*a*) method were lower than those by the (*b*) method. Seeing that other cereals contain nitrogenous matter but yield no gluten, the (*b*) method is useless for present purposes in those cases. However, here are the Nitrogen and Gluten figures for the six flours now under consideration :—

	Nitrogen.		Dry Gluten.		N. × 5·68.	
Sample.	Dec., 17.	July, 18.	Dec., 17.	July, 18.	Dec., 17.	July, 18.
A.	1·806	1·610	9·13	9·31	10·26	9·14
B.	1·806	1·680	9·39	8·99	10·26	9·54
C.	1·890	1·778	9·08	8·82	10.74	10·10
D.	1·866	1·694	8·26	6·24	—	—
E.	1·876	1·674	7·76	6·54	—	—
F.	1·848	1·568	7·30	6·61	—	—

The changes in the gluten figures of the pure wheaten flours by the two methods of estimating are as follows :—

	Washing.	N. × 5·68.
Sample A.	+0·18	−1·12
„ B.	−0·40	−0·74
„ C.	−0·26	−0·64

Just for what it may be worth, there is in these figures, a suggestion that mites may preferably assimilate the nitrogenous bodies which do not go to form gluten.

Behaviour during Panary Fermentation.

In my opinion, some investigators use the term "strength" to connote essentially different characteristics. When I use that term, I am referring to a flour's capacity for yielding large well-shaped loaves. The size (volume) of a loaf depends on two principal points :—

(1) The evolution during panary fermentation of a quantity of gas sufficient to overcome the great leak, and to thoroughly inflate the dough.

(2) The gas retaining capacity of the dough.

The first point is or can be under the control of the miller and/or the baker. The crux of the position resides in the second point. The strength of a flour is a most important quality. With these ideas in my mind, I tested under various conditions the behaviour of these flours during panary fermentation. For the purposes of these tests I used a baking method of which the principal points are these: 0·5 per cent. distillers' yeast, 1¼ per cent. salt, 8 hours' fermentation at 80° F. Some of the six flours yielded without the assistance of yeast foods a sufficiency of gas, the others did not. So I made two sets of baking tests at both periods, one December, 1917, and the other, July, 1918. The volume of loaf, stated in c.cs., is as follows :—

	December, 1917.		July 1918.	
	No Yeast. Food.	With Yeast. Foods.	No Yeast. Food.	With Yeast. Foods.
Sample A.	2,525	2,725	2,525	2,650
,, B.	2,350	2,675	2,625	2,625
,, C.	2,150	2,425	2,350	2,625
,, D.	2,050	2,100	1,775	—
,, E.	2,200	2,400	2,450	2,500
,, F.	2,075	2,150	2,275	2,375

This table can engender many remarks on technical points, but for the purposes of the Committee, all I need say is that it indicates no degeneration of baking quality due to mites. A great change had taken place in the D. flour, and it was distinctly sour in July, 1918, but these factors already recorded herein must be remembered. Its 20 per cent. of barley flour was obtained from grain which originally contained a high percentage of natural moisture, and was to some extent sprouted, and the moisture of the whole flour had been raised between December, 1917, and July, 1918, whereas the moisture of the other five flours had decreased during that period. It seems to me, therefore, that its degeneration may be, and probably was, not due to the presence of mites.

Conclusion.

It is believed that mites attack the nitrogenous matter of flour, and in that or some other way make the flour, apart from their mere presence, unfit for the manufacture of bread. The flour sent to me for examination prior to these tests was so unfit, but I formed the opinion from internal evidence, that it was made principally or extensively from poor wheats which probably were unsound, and that the flour itself probably contained a high percentage of water at the time of manufacture. In framing the programme of the tests recorded herein, I postulated the use of reasonably sound grain, and a moderate or low water content, so that the effects which might be wrought by mites should not be intermingled with or obfuscated by those due to unsoundness and high water content. Apart from flour D., the changes due to keeping were not abnormal, and the improvement in baking qualities which usually are due to keeping, have not been offset or balanced by any ill effect due to mites. Nor has the admixture of rice flour and maize flour caused degeneration due to mites.

I sifted the flours on their return from Liverpool, and again found that the mites could be removed by sifting through No. 14 silk, and that substantially no mites reappeared in the flour which had passed through the sieve. Some of the pre-war flours of commerce contain a very high percentage of particles which would pass through that silk, and if these tests are continued, it may be desirable to work with flours in which the size of particle is as small as that. In that way one could ascertain the proportion of mites by the actual weight each flour contained. In the tests recorded herein, we were working with flours which contained a large and variable proportion of particles which would not pass through No. 14 silk, so that it was impossible to ascertain with precision whether they were greatly infected with mites, or to what extent they were so infected.* From some points of detail observed during the work, I have a suspicion, I cannot put it higher, that the mites would breed, or at any rate multiply more readily, in flour of higher water content.† In any future tests I should like to work with, or include in the set, not only flours containing exclusively fine particles, but I would also like to test the point as to increased water content in its relation to propagation of mites.

The outstanding result of the tests recorded herein is that under the specified conditions, the quality of the flour as raw material for the manufacture of bread, has not degenerated.

I have only tested these flours on a laboratory scale, but it appears that mites can be separated from flour by "redressing," that is to say, by passing it through some process of sifting, and in that way a substantial or large proportion of flour may be recovered for prompt commercial use, free from mites.

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* The flour though heavily infested with mites, and the accompanying fæcal elements had not reached the characteristic stage of degeneration which invariably occurs in the later stages of mite-infested flour (*see* also Prof. Beattie's Report, p. 42).—R.N.

† They certainly do so (*see* p. 28).—R.N.

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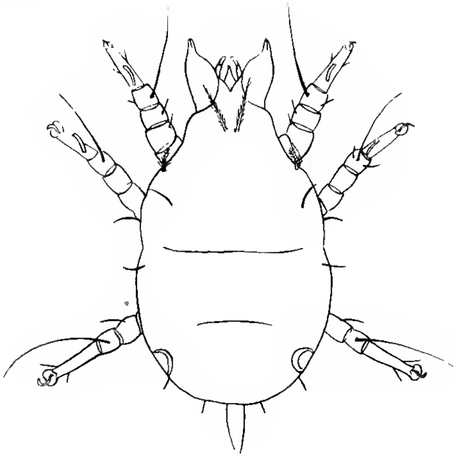

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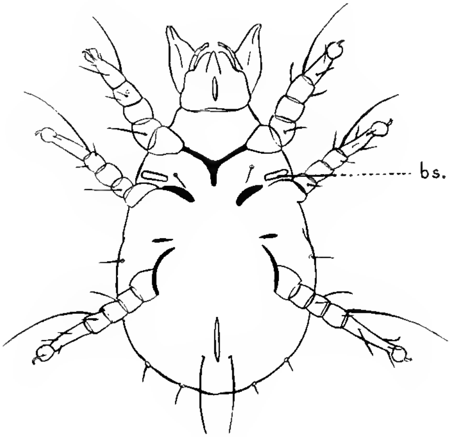

HMD

Aleurobius farinae.

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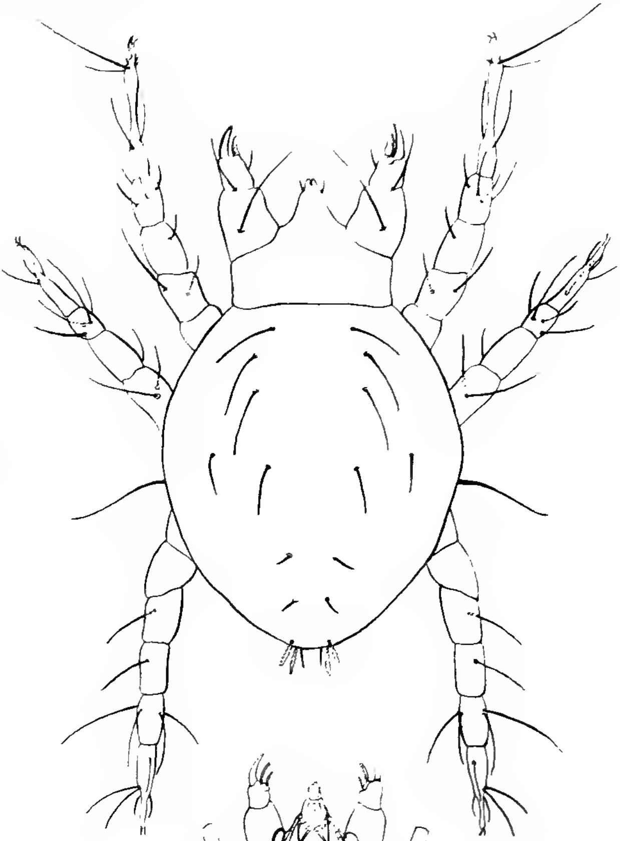

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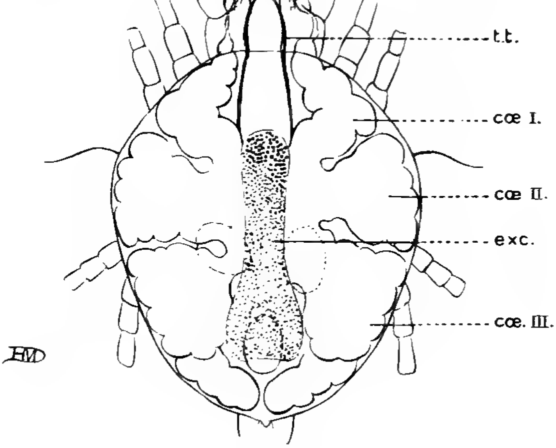

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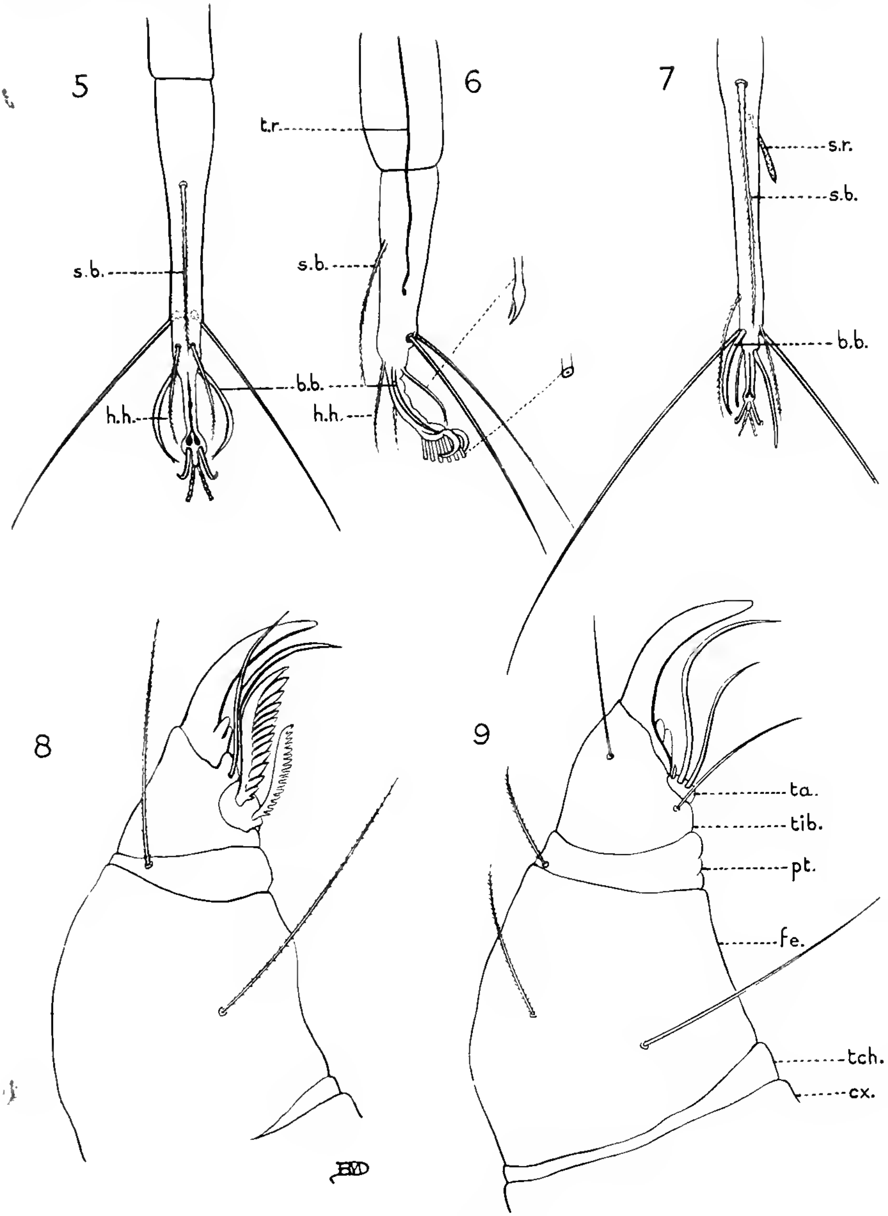

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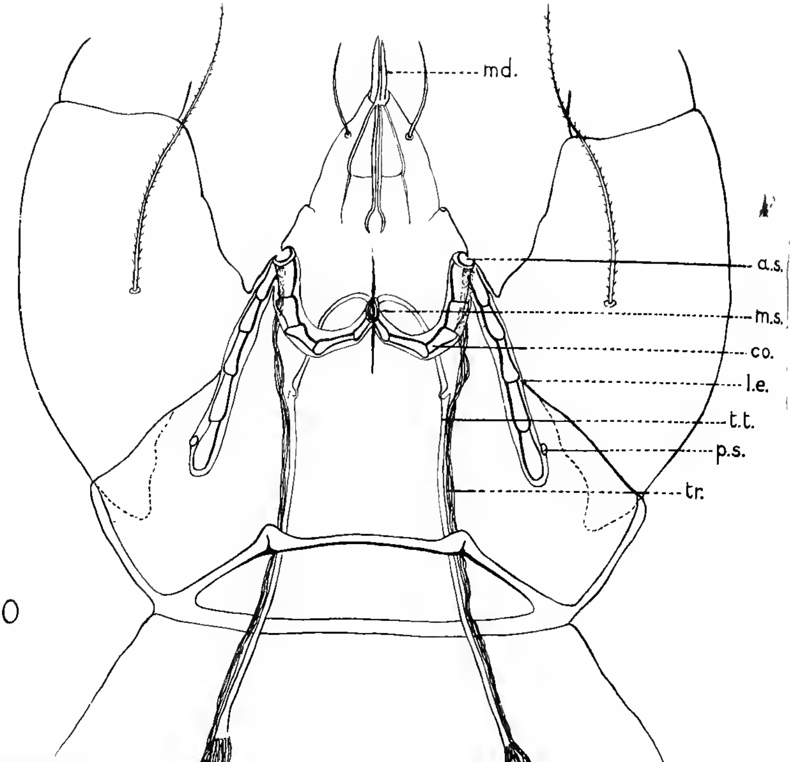

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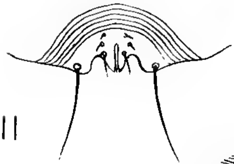

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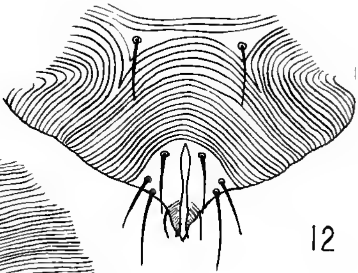

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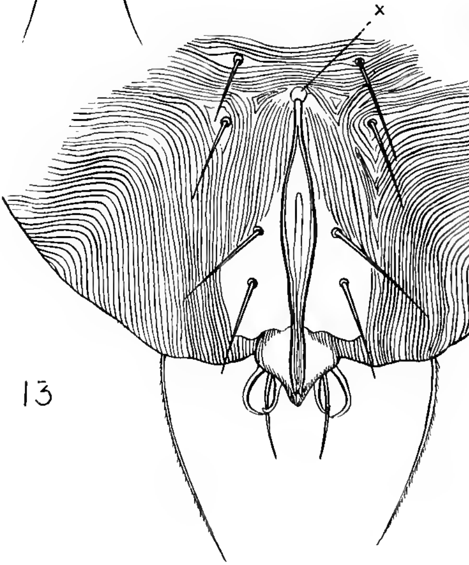

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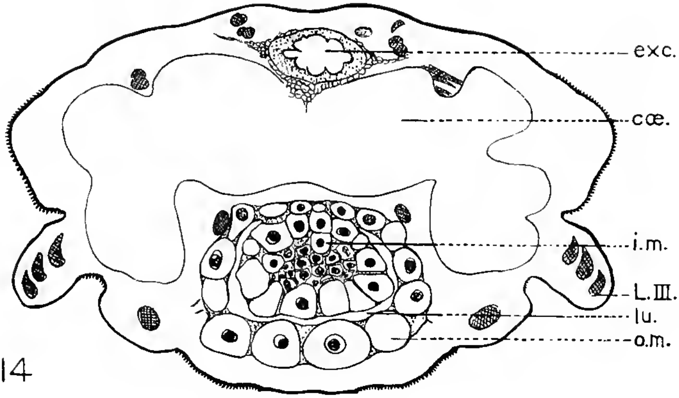

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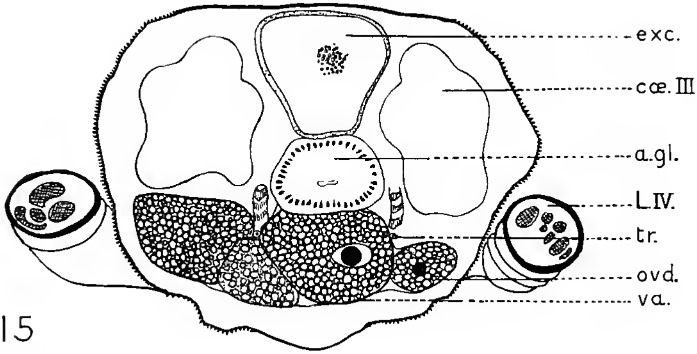

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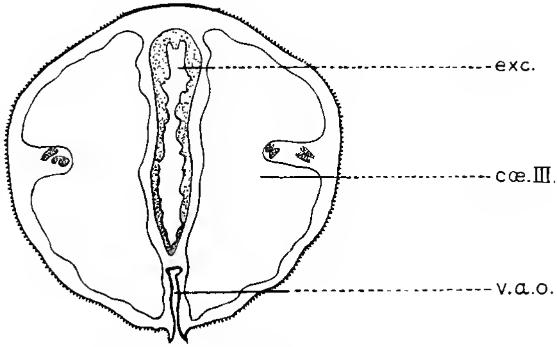

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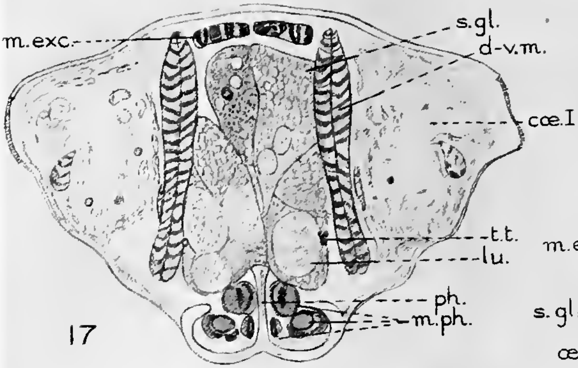

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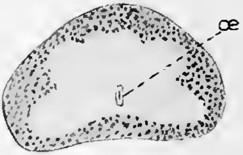

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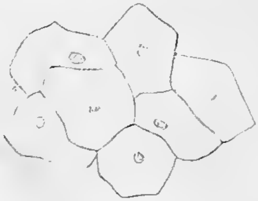

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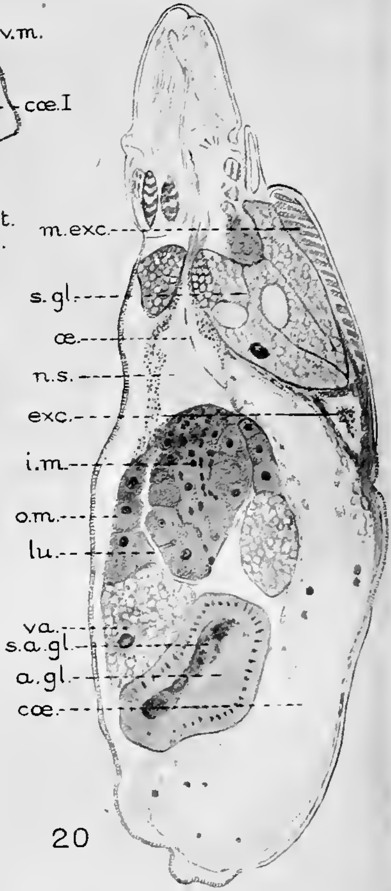

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Cheyletus eruditus.

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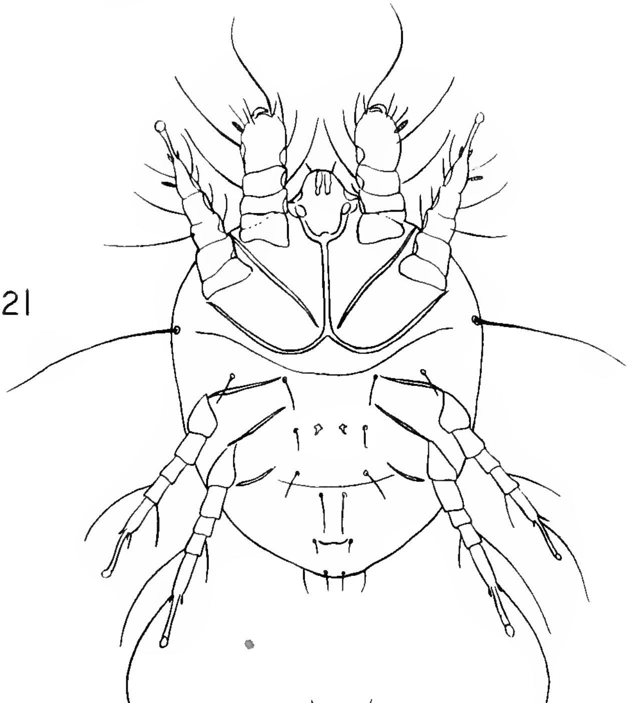

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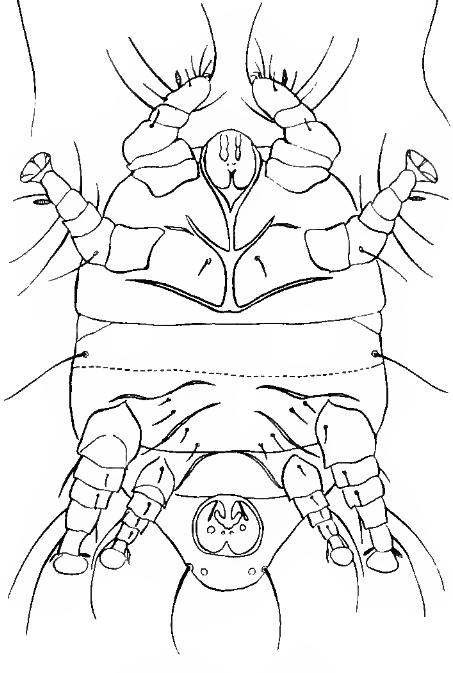
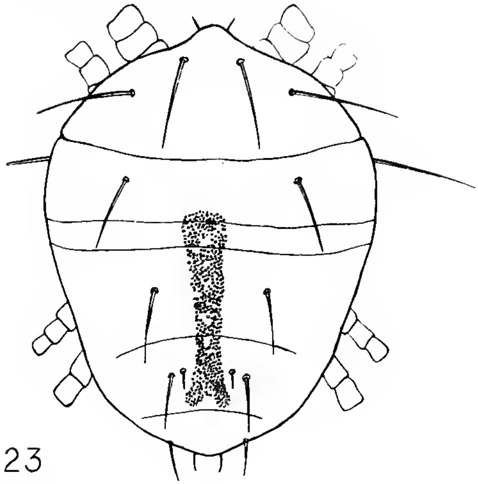


Acarophenax tribolii.



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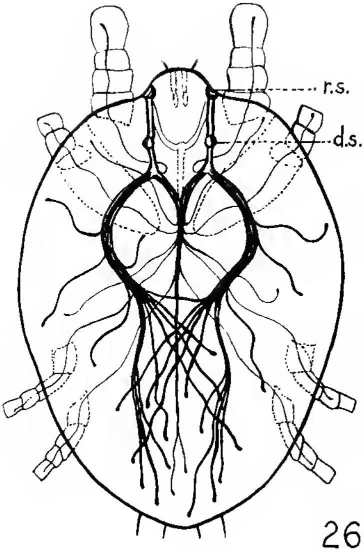

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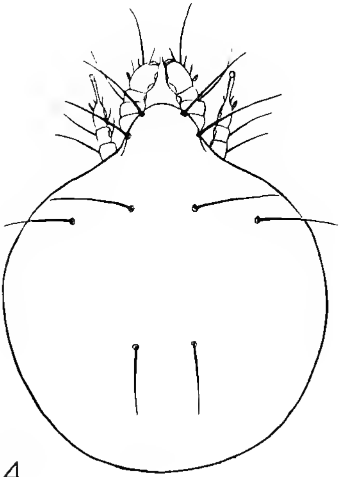

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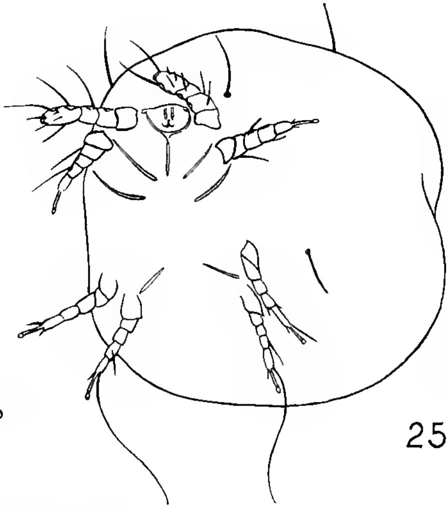

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Acarophenax tribolii.

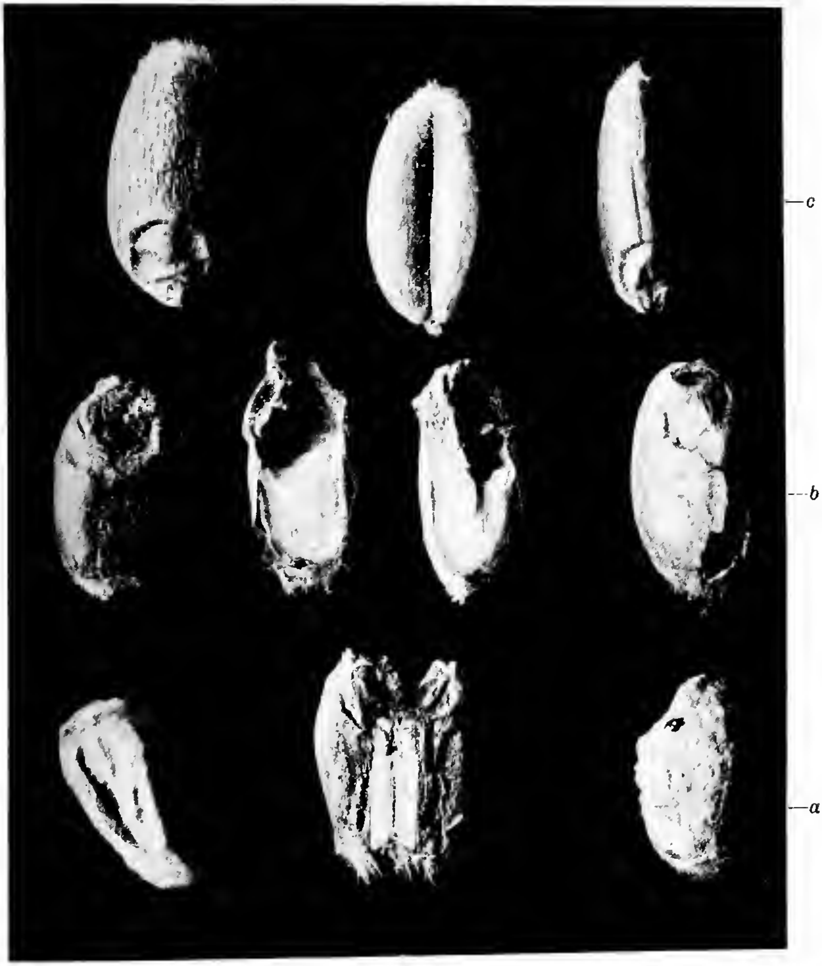

Fig. 27.

a and *b*—GRAINS INJURED BY *Aleurobius farinae*; *c*—SOUND GRAINS.

× 6.

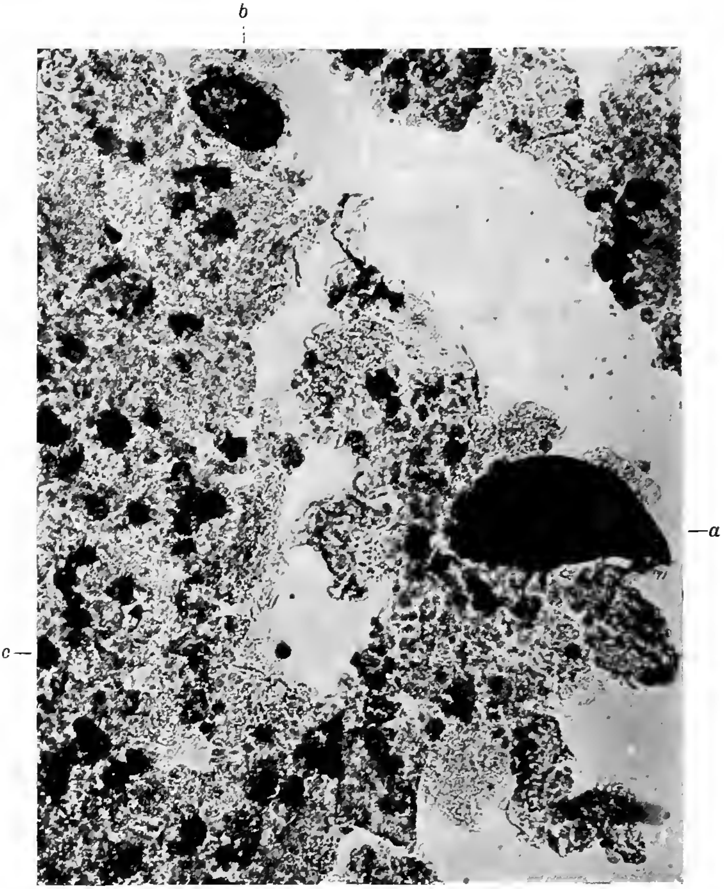

Fig. 28.

MICROPHOTOGRAPH OF STATE FLOUR HEAVILY MITE-INFESTED.

a—acarid; *b*—egg of acarid; *c*—fæcal pellets.

× 100.

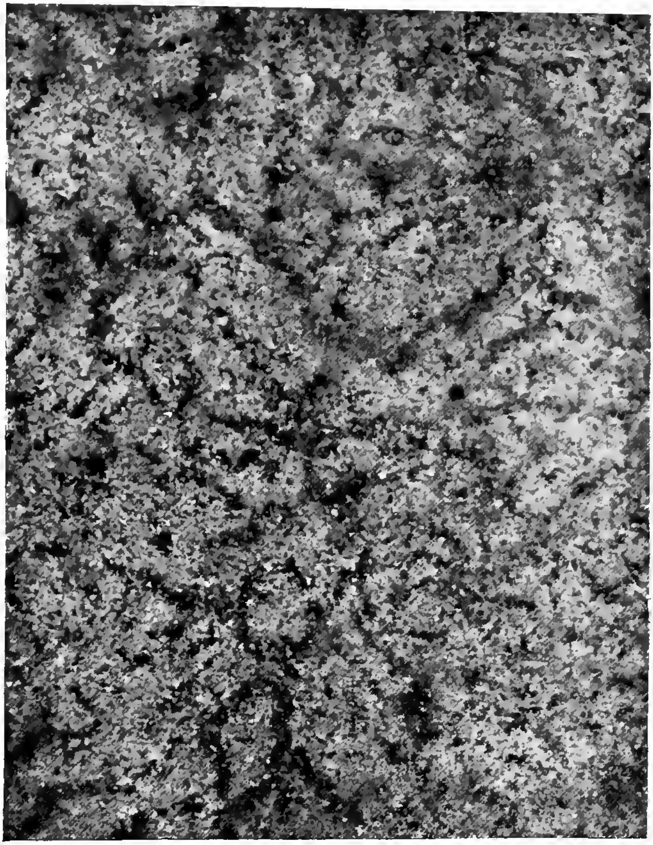

Fig. 29.

BURROWS OR WORKINGS PRODUCED BY ACARIDS IN FLOUR.

× 10

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REPORTS OF THE GRAIN PESTS (WAR) COMMITTEE.

No. 3.

LONDON:
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November, 1918.

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CONTENTS.

1. Report on the Effect of Air-tight Storage upon Grain Insects.—Part II. By Prof. Arthur Dendy, F.R.S., and H. D. Elkington, B.Sc.
2. Experiments with Two Secondary Grain Pests, showing their Inability to Attack Sound Wheat. By Prof. Arthur Dendy, F.R.S.
3. Observations on the Attraction of Certain Grain Beetles, especially Weevils, by Water. By Prof. Arthur Dendy, F.R.S.

REPORT ON THE EFFECT OF AIR-TIGHT STORAGE UPON GRAIN INSECTS.—PART II.

By ARTHUR DENDY, D.Sc., F.R.S.,
Professor of Zoology in the University of London,

AND

H. D. ELKINGTON, B.Sc., F.I.C.

The present instalment of this Report contains further experimental evidence as to the efficiency of hermetical sealing as a means of destroying insect pests. In the Part already published,* attention was confined almost entirely to the adult weevils, *Calandra oryzæ* and *Calandra granaria*, though some evidence was adduced to show that hermetical sealing was equally effective in the case of the immature stages of the latter species (*see* Experiment D).

We have now made more exact experiments with the immature stages of both species of weevil, and are in a position to state that they are quite as susceptible to this method of treatment as the adults, probably even more so.

We have also extended our experiments to a number of other grain beetles, viz., *Rhizopertha dominica* and *Trogoderma khapra*, which are both grain pests of primary importance, and *Tribolium castaneum*, *Læmophlœus* sp. and *Silvanus surinamensis*, which, although occurring abundantly in damaged grain, are probably to be regarded as of quite secondary importance. We have found that all these are destroyed by hermetical sealing under the same conditions as the true grain weevils, and that the same is true of the common mites which sometimes make their appearance in enormous numbers in our cultures.

We have even ventured to extend our experiments to two insects which are undoubtedly flour- rather than grain-insects, and therefore somewhat outside the scope of our investigations as originally laid down. The first is *Gnathocerus cornutus*, a small beetle which again proved to be susceptible to the treatment both in the adult and in the larval condition. The second is the notorious flour-moth, *Ephestia kühniella*, so destructive in its larval stage to cereal products, and it affords us much satisfaction to be able to record the inability of these most noxious larvæ to withstand hermetical sealing, at any rate under the conditions of our experiments.

It still remains, if possible, to perform an experiment with weevilled wheat on a large scale, and we hope to be able to carry out this intention in the near future. It seems safe to say already, however, that air-tight storage is probably the best method of preserving all grain and cereal products from the attacks of any kind of insects or mites, and, of course, the same must apply in the case of larger animal pests such as rats and mice.

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* Report of the Grain Pests (War) Committee, No. 1.

We are well aware, of course, of the apparent failure of this method as applied to army biscuits and of the immense amount of damage, especially by *Ephestia kühniella*, reported as taking place in hermetically sealed tins. Mr. Hartley Durrant and Colonel Beveridge* make the following statement with regard to this subject. "The biscuits are packed in tins, hermetically sealed, and enclosed in wooden cases to prevent injury; it was, therefore, obvious that if insects could be found within intact tins it would be demonstrated at once that infestment must have taken place in the factories, and not subsequently. With a view to determine the origin of infestation, sample tins were withdrawn from stocks at various stations abroad, for inspection at Woolwich by experts, and tins, which after careful examination had been pronounced intact, were found to contain *Ephestia kühniella*, *&c.*, in various stages of development; thus proving conclusively that infestation had taken place in the factories before the tins were soldered, and indicating that preventive or remedial measures must be undertaken in the factories themselves."

We do not, of course, wish to speak dogmatically until further experiments have been carried out, but in view of our own experience, both with Ephestia and with other insects, we doubt whether, in really hermetically sealed tins, any serious damage could arise. Of course, as we have shown to be the case with the weevils, a very small leak might suffice to keep the insects alive indefinitely, but it ought not to be difficult to test the tins after soldering by immersing them in hot water, when the expansion of the air inside would cause an escape of bubbles if the sealing were imperfect. We would suggest to the army authorities that further investigations should be undertaken with a view to determining how far damage can take place in really air-tight tins, in which, of course, the air-space is kept as small as possible.

We reserve the scientific discussion of the factors concerned in bringing about the lethal effects, now observed in so many cases, for a separate part of our Report.

EXPERIMENT A′.

The effect of sealing wheat containing Larvæ and Eggs of Calandra oryzæ *for twenty-eight days at 24° to 27° C.*

For the purposes of this experiment weevil-free wheat (No. 1 North Manitoba) was infected with *Calandra oryzæ* so as to ensure the presence of larvæ and eggs.

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* "Report on the Temperature reached in Army Biscuits during Baking, especially with Regard to the Destruction of the imported Flour-moth, *Ephestia kühniella* Zeller." Reprinted with Additions. British Museum (Natural History), 1918.

Two flasks, A and B, each of about 200 c.c. capacity, were almost completely filled with wheat, and 100 *Calandra oryzæ* added to each. The flasks were covered with cambric and placed in the incubator (24° to 27°) on April 9. The weevils were allowed to remain in contact with the wheat for a fortnight to give time for the females to lay their eggs.

On April 23 the contents of the flasks were turned out and the weevils counted. Flask A contained 96 live weevils and 4 dead, while in B there were 97 live weevils and 2 dead.* The adult weevils, alive and dead, were removed from both flasks and, after the grain had been replaced, A was hermetically sealed, while B was covered with cambric to serve as a control. Both were replaced in the incubator on April 23. On May 15 one living adult weevil was observed in B.

On May 21, after 28 days' sealing, flask A was opened, and its contents turned out and examined. No sign of weevils, live or dead, could be seen. The grain was replaced in the flask, which was now merely covered with cambric and re-incubated at 24° to 27° C.

On the same day the contents of the control flask (B) were examined and 130 live adult weevils were counted, while many more were in the grains. The weevils were all removed and the wheat replaced in the flask for further incubation.

On May 30, 343 additional live adult weevils were found in flask B and many more were in the grains. Since the first live weevil appeared on May 15 and the final count was made on May 30, it is reasonable to assume that the 473 live weevils which had appeared by the latter date could only have been hatched out from the eggs laid by the females of the original 100 weevils, which had been in contact with the grain from April 9 to 23.

Flask A remained in the incubator covered with cambric from May 21 to June 21, so that any eggs or any larvæ that were still alive should have time to develop. The wheat was turned out and examined on June 21, but no sign of weevils, live or dead, could be seen.

This experiment shows that the hermetical sealing for 28 days, at 24° to 27° C., of grain infected by eggs and larvæ of *Calandra oryzæ* was sufficient to destroy the latter and to render the wheat insect-free, while grain similarly infected and exposed to air for 50 days at the same temperature yielded 473 live adult weevils.

EXPERIMENT B'.

The effect of sealing wheat containing Larvæ and Eggs of Calandra granaria *for twenty-eight days at 24° to 27° C.*

This experiment was also commenced on April 9. Two flasks, C and D, each of 200 c.c. capacity, were almost completely filled with wheat (No. 1 North Manitoba) and 100 *Calandra granaria* were placed in each. The flasks were covered with cambric and incubated at 24° to 27° C.

---

* The missing weevil was either inside a grain or else a miscount had been made.

till April 23, when the contents of the flasks were turned out and examined and the weevils counted and removed. Flask C contained 93 live adults and 5 dead, while in D there were 97 live adults and 3 dead. Flask C was then hermetically sealed, while D was covered with cambric. Both flasks were returned to the incubator. On May 18 4 live adults were seen in D, but none in C, and on May 21 the contents of both flasks were turned out and examined. In C no sign of weevils could be found, but from D 142 live adults were removed. The wheat was replaced in its respective flasks, and these were covered with cambric and replaced in the incubator. On May 30 they were again examined, with the result that, while C was found to be free from weevils, D yielded 296 live adults. Flask C, which had been sealed for 28 days, remained open to the air in the incubator from May 21 to June 21, when its contents were again examined. No sign of weevils could be seen. One hundred grains taken from a representative sample were cut across. Only a few had minute cavities, the rest being perfectly whole. The sealing had evidently completely arrested the development of the larvæ at an early stage.

Experiment C′.

The effect of sealing wheat containing Larvæ and Pupæ of Calandra oryzæ *for twenty-five days at* 31° *C.*

On April 5 some grain, rather badly eaten, was taken from a pure stock culture of *Calandra oryzæ* and sieved to free it from loose weevils. One hundred and ninety-two grains of the well-mixed wheat were placed in each of two small specimen tubes, so as to fill them completely. One tube, A, was hermetically sealed, the other, B, being covered with cambric. Both were placed in the incubator at 31° C. One live weevil was observed in the control tube (B) on April 8, and by April 12 8 could be seen.

On April 30 both tubes were turned out and their contents examined. A contained 5 dead adult weevils, while B had 51 live adults and 6 dead. The dead weevils in both tubes were incubated for 48 hours, but failed to revive. The live weevils in tube B were removed, and the wheat in both tubes replaced. Both were now covered with cambric and incubated at 31° C.

On May 17 the contents of the tubes were again examined, when 17 live adults were removed from B, but no signs of weevils, live or dead, could be seen in A. The grains were replaced in their respective tubes and a final examination was made on June 1. Six live adults were removed from B, but, as before, no weevils were found in A.

During the 57 days that the open tube (B) was incubated 74 live adult weevils were removed, in addition to 6 dead. We do not suggest that all these developed from larvæ present at the commencement of the experiment, but it is highly probable that the 51 live adults and 6 dead found on April 30 were produced from eggs or larvæ present in the grains when first placed in the tube. Dissection of the grains from tube A (which had originally been sealed) showed that 15 contained *dead* adults and 42 contained *dead* larvæ or pupæ. This experiment once more clearly shows that hermetical sealing kills weevils whether in the larval, pupal or adult state.

EXPERIMENT D′.

The effect of sealing 100 *selected grains of wheat punctured by* Calandra oryzæ *for forty-one days in a relatively large air-space at* 31° C.

On April 26 some wheat (No. 1 North Manitoba) from a 16-days old culture of *Calandra oryzæ* was carefully examined with a lens, and grains which were punctured, but otherwise whole, were picked out. These presumably infected grains were thoroughly mixed to ensure fair sampling, and 100 grains were counted out into each of three test-tubes, A, B and C, of about 20 c.c. capacity. The tubes A and B were covered with cambric, while C was hermetically sealed. They were all placed in the incubator at 31° C. The tubes were examined from day to day, and signs that development was proceeding in A and B were observed, but the wheat in C remained apparently unchanged.

On May 15, that is 19 days from the commencement of the experiment, adult weevils were observed in A and B. They were removed from both tubes, and examination and removal of adults were repeated daily. By May 24, 47 adults had been removed from A, 42 from B, while the wheat in C, still sealed, was as clean as when placed in the tube. By June 3 another 5 weevils had emerged from the grain in B. Up to June 26 no further weevils had made their appearance, so it appears that 47 per cent. of the grains in both A and B must have been infected with weevils, and that these were in a very immature condition is proved by the fact that they required a minimum of 19 days to complete their development to the time of emerging from the grain.

On June 6, after having been sealed for 41 days, tube C was opened and all the wheat grains cut in half. Although punctured and with small cavities continuing the puncture inwards, no recognisable larvæ could be found in any of them. This also proves that the larvæ must have been very young when the grain was sealed; probably in some cases, at any rate, the eggs had not yet been hatched, and they were probably killed within a few days of sealing. This is rather remarkable, as there was a very large space in the sealed tube in proportion to the number of infected grains and, as a matter of fact, analysis showed that the air in the tube at the close of the experiment contained only 3·93 per cent. CO_2. This experiment shows that the early stages of *Calandra oryzæ* are probably a good deal more susceptible to the effects of hermetical sealing than are the adults.

EXPERIMENT E′.

The effect of incubating and subsequently sealing at 31° *C. a commercial sample of wheat slightly infected with* Rhizopertha dominica.

A supposed clean sample of Indian wheat (No. 2 Club Calcutta) was supplied by the Landed Grain Committee of the Royal Commission on Wheat Supplies on November 16, 1917.

On November 17 a small glass cylinder filled with this wheat and covered with muslin* was placed in the incubator (kept at about 31° C.) to test its freedom from insects.

On November 21 an active specimen of *Rhizopertha dominica* was observed in the cylinder.

On January 15, 1918, the contents of the cylinder were turned out and three living Rhizopertha were found. They were all replaced and put back with the wheat in the incubator.

On March 26 the wheat was again turned out and examined. It appeared to be still in good condition, with no signs of mildew, but many living Rhizopertha were found, some inside and some outside the grains (a good many on the inner surface of the cambric cover). There was also a good deal of flour produced by their activity and many damaged grains. The whole was well mixed together and divided into two approximately equal portions. Each portion was placed in a separate cylinder, which was filled up almost to the top with clean wheat from the original sample.† The two cylinders employed contained each about 120 grammes of wheat. One (A) was covered with cambric, the other (B) was sealed. Both were replaced in the incubator.

On April 2 plenty of living Rhizopertha were visible in A, but all those visible in B appeared to be dead.

On April 18 the contents of the two cylinders were turned out and carefully examined. The unsealed cylinder (A) contained 125 live Rhizopertha and 37 dead ones, while probably a few more remained unnoticed in the wheat grains. The sealed cylinder (B) contained no living Rhizopertha and 86 dead ones, probably a few more remaining unnoticed in the grains. The dead insects from B were placed in a ventilated test-tube and incubated to give them a chance of recovery, but without result. The contents of both cylinders were replaced and the cylinders covered with cambric and returned to the incubator. (The dead Rhizopertha from B were replaced on the following day.)

On May 22 the contents of the two cylinders were again turned out and examined. 243 live Rhizopertha were found in A, mostly between the grains and on the inside of the cover, but a good many were extracted from the interior of the grains and a few must have remained undiscovered. Eighty-four dead Rhizopertha were found loose between the grains. The grain was dry and free from mildew and mites but contained a good deal of flour milled by the insects. Cylinder B, on the other hand, contained no live insects, both adults and larvæ had evidently been completely destroyed by sealing. It was also free from mites and mildew.

The results of this experiment are very instructive from the practical point of view, for they show, in the first place, that an apparently clean sample of wheat may become badly infected with Rhizopertha if kept for a few months at a warm temperature and in a moist atmosphere, and, in the second place, that, having become badly infected, it may be completely cured by hermetical sealing (in this case for 23 days at 31° C.). The grain that had been sealed, still kept at 31° C., remained free from insects for four weeks and six days after the seal was opened, after the lapse of which period it was permanently removed from the incubator, as it seemed safe to assume that the cure was complete. It was, however, kept at room temperature for a further period of nine weeks (May 22–July 25) without any live insects showing themselves.

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* Afterwards replaced by cambric.

† The remainder of the original sample, amounting to about 156 grammes, was sifted and carefully examined on this date, having been kept in the laboratory at room temperature since it arrived. The remains of only one Rhizopertha and one bug (?) were found and no insect-damaged grains were seen.

EXPERIMENT F′.

The effect of sealing wheat containing 100 Rhizopertha dominica *for three days at 31° C.*

On April 16 two small flasks of about 75 c.c. capacity were nearly filled with wheat (No. 1 North Manitoba) and 100 adult *Rhizopertha dominica* added to each. One flask (A) was sealed at room temperature and the other (B) covered with cambric. Both flasks were placed in the incubator at 31° C., at 4 p.m. On April 17, at 10.30 a.m., there were normal activity and signs of feeding in both flasks. On the following day, however, at 10.20 a.m., no movement could be seen in A (though many Rhizopertha were visible), while in B there was great activity. On the 19th, at 10.30 a.m., there was still no movement in A. At 2.30 p.m. the contents of both flasks were turned out and examined, with the result that A was found to contain 100 dead Rhizopertha, which failed to revive even after three days in the incubator at 31° C., while B contained 98 live Rhizopertha and 3 dead. The extra beetle found in B was probably due to a miscount, since the wheat used had been tested and found to be insect-free.

Thus it appears that Rhizopertha is very quickly destroyed by hermetical sealing in a small air-space.

EXPERIMENT G′.

The effect of sealing Larvæ of Trogoderma khapra *for six days at 31° C.*

On May 24 20 grains of No. 1 North Manitoba wheat were placed in each of three small specimen tubes, A, B and C, each of about 2·5 c.c. capacity. Ten Trogoderma larvæ were added to each tube. A was hermetically sealed, while B and C were covered with cambric. The three tubes were placed in the incubator at 31° C. at 3.30 p.m. On the following day (May 25) no movement of the larvæ was discernible in A, while those in B and C were quite active and feeding. The tube B, after having been in the incubator over night exposed to the saturated atmosphere therein, was sealed at 11.35 a.m. On the 27th no movement could be seen in A or B, though the larvæ in C were normally active.

On May 28, there still being no detectable movement in A, this tube was opened and the 10 apparently dead larvæ removed and incubated. By 10.20 a.m. on the next day three larvæ had revived, but the others failed to revive after three days' incubation.

Tube A had only been sealed for four days, so it was thought advisable to leave B sealed for six days. On May 31 B and C were both opened, 10 inert larvæ were found in B, while 10 active larvæ were found in C. The former were incubated for three days at 31° C. but failed to revive.

It appears, therefore, that *Trogoderma khapra* in the larval state is killed by hermetical sealing in quite a short time, provided the air-space is very small; but experiments with larger tubes lead us to suspect that it is a good deal less susceptible than Calandra. Unfortunately our stock of Trogoderma is not at present sufficient to enable us to make more exhaustive experiments.

EXPERIMENT H′.

The effect of sealing Tribolium castaneum *for two days at* 31° *C.*

On May 15 three test-tubes, A, B and C, each of about 15 c.c. capacity, were three-quarters filled with crushed No. 1 North Manitoba wheat. Fifty *Tribolium castaneum* were placed in each tube, A was sealed at 12.15 p.m., while B and C were covered with cambric. All three were placed in the incubator at 31° C. at 12.30 p.m. On the following day, at 10.15 a.m., there was no recognizable movement of the beetles in A, though many were visible; but those in B and C were extremely active.

Tube B, which had now been exposed to the moist air of the incubator over night, was sealed at 12.30 p.m. on May 16. On the next day the tubes were examined at 10.25 a.m., and, while no movement could be detected in either A or B, the beetles in C were still very active indeed.

The contents of the three tubes were turned out and examined at 12.35 p.m. on May 17. A contained 50 Tribolium which failed to revive under favourable conditions; in B 50 inert beetles were found, all of which revived by 5.30 p.m. on the same day; C contained 50 live and extremely active individuals.

In this experiment the period of torpidity had passed into death in the case of tube A, sealed for 48 hours, but not in the case of B, which only remained sealed for 24 hours. There can be no doubt that had B remained sealed for a longer period the insects would have been killed in this case also.

EXPERIMENT K′.

The effect of sealing Læmophlœus sp. *for three days at* 31° *C.*

On April 30 two test-tubes, A and B, of about 15 c.c. capacity, were three-quarters filled with crushed No. 1 North Manitoba wheat and

100 Læmophlœus placed in each. Both were covered with cambric and placed in the incubator at 31° C. On the following day the beetles were equally active in both. A was hermetically sealed at 12.30 p.m., while B served as control. Both were replaced in the incubator. On May 2, at 12.15 p.m., only slight movement in one beetle could be seen in the sealed tube, although many were visible. The individuals in B, on the other hand, were quite active. On May 3, at 10.30 a.m., the contents of the tubes were turned out and examined. A was found to contain only 99 dead Læmophlœus, while in B 83 live beetles and 17 dead were found. The dead beetles found in both tubes were incubated under favourable conditions, but failed to revive.

EXPERIMENT L′.

The effect of sealing Silvanus surinamensis *for two days at* 31° *C.*

On May 7 two test-tubes, A and B, each of about 15 c.c. capacity, were three-quarters filled with crushed No. 1 North Manitoba wheat and 100 Silvanus placed in each. Both were covered with cambric and placed in the incubator at 31° C. at 4 p.m. On the following day the beetles were extremely active in both tubes. A was hermetically sealed at 12 p.m., B serving as control. At 10.15 a.m. on May 9 the beetles in A were quite motionless, while those in B were very active indeed. On May 10, at 10.45 a.m., the contents of both tubes were turned out and examined. A was found to contain 100 dead Silvanus, while in B there were 100 live and very active individuals. The dead Silvanus from tube A were incubated for 48 hours, but failed to revive.

EXPERIMENT M′.

The effect of sealing Adults of Gnathocerus cornutus *for five days at* 31° *C.*

On June 17, 10 adult specimens of *Gnathocerus cornutus* were placed with a little flour in each of two test-tubes of about 50 c.c. capacity. Pure, moist air, free from carbon dioxide, was passed through one tube (A) which was then hermetically sealed at 3.50 p.m. The other tube (B) was covered with cambric to serve as a control, and both were placed in the incubator at 31° C. On the two following days movement could be observed in the beetles in both tubes, though they were rather sluggish and appeared to sham death very successfully. On June 20 movement was still observed in 5 individuals in the sealed tube, while those in the control appeared to be normal. At 9.50 a.m. on the 21st no movement at all could be detected in tube A.

Both tubes were opened on the 22nd at 10.45 a.m. Ten dead individuals were found in A, while B contained 8 live beetles and 2 dead. The 10 dead beetles from A were incubated, but failed to revive. In this experiment the air-space was large in proportion to the number of beetles used, and yet 5 days' sealing was sufficient to destroy them completely.

EXPERIMENT N′.

The effect of sealing Larvæ of Gnathocerus cornutus *for three days at 31° C.*

On June 17 20 active Gnathocerus larvæ were placed with a very little flour in each of two test tubes, A and B, of about 20 c.c. capacity. Pure, moist air, free from CO_2, was passed through tube A, which was then sealed at 3.35 p.m., while B was covered with cambric. Both tubes were placed in the incubator at 31° C. about 3.50 p.m. At 10 o'clock on the next day the larvæ in A were quite active and the cork had been attacked in several places. Those in B were equally active. On June 19, at 10.15 a.m., the larvæ in A were motionless and appeared shrivelled, but those in B were still very active.

The tubes were opened at 3 p.m. on June 20. Twenty shrivelled and dead larvæ were found in A, which failed to revive under favourable conditions, while 17 live and three dead larvæ were counted in B. In this experiment it should again be noted that the air-space was large in proportion to the number of insects present, and yet three days' sealing was sufficient to kill them.

EXPERIMENT O′.

The effect of sealing Larvæ of Ephestia kühniella *for five days at 31° C.*

On June 17 ten Ephestia larvæ were placed with a very little flour in a test-tube (A) of about 20 c.c. capacity and pure, moist air, free from CO_2, was passed through the tube. The tube was sealed at 4.15 p.m. About the same time seven larvæ were placed in a similar tube (B) with a little flour and the tube covered with cambric to serve as a control. Both tubes were placed in the incubator (31° C.) at about 4.30. On the following day, at 10.10 a.m., the larvæ in the sealed tube were alive, but very sluggish in their movements, while those in the control were also very sluggish. At 10.15 a.m. on June 19 no movement could be seen in the sealed tube, but movement in the control could still be detected.

A was left sealed till June 22, when both tubes were opened. Ten dead and shrivelled larvæ were found in A, while B contained six live and one dead larvæ. The ten dead larvæ from A were incubated for 48 hours under favourable conditions, but failed to revive.

EXPERIMENT P′.

The effect of sealing flour badly infested with Larvæ of Ephestia kühniella *for seven days at 29° to 30·5° C.*

On April 25 a culture of *Ephestia kühniella* was started by placing some of the moths in a cylinder containing flour. On July 15 the culture was found to be swarming with larvæ, many of which were visible just inside the glass in little tunnels in the matted flour, where they could easily be observed. There were also a small number of pupæ and some dead moths, but no live moths. The larvæ were in different stages of development, say, from ¼ inch to ½ inch long, and a large part of the flour was matted together with their web. The whole was turned out and divided into two approximately equal and similar portions. Each portion was placed in a clean glass cylinder, covered with cambric, and replaced in the incubator at about 30° C. Plenty of live, active larvæ were observed in each cylinder after covering. The cylinders were about 136 mm. in height and 42 mm. in diameter (inside measurements), and as they were rather less than half filled with the larva-infested flour there was a relatively large air-space.

On the following day (July 16) numerous larvæ had again taken up their positions in tunnels in the flour against the glass, and in both cylinders movements were observed. The condition of the larvæ being now apparently quite normal, without further disturbance one cylinder was sealed at 1.45 p.m., while the other was left covered with cambric as a control. Already at 5.15 p.m. all movement was apparently suspended in the sealed cylinder.

On the 17th, at 11.30 a.m., normal activity was observed in the control, but in the sealed cylinder all the larvæ appeared to be quite dead, and in a nicely extended condition. On the 23rd many of them, though apparently dead, were found to be still fairly turgid, a few which happened to be on top of the flour rolling backwards and forwards when the cylinder was tilted, and showing, to the naked eye, no signs of decay. In the control cylinder, on the other hand, normal development had proceeded.

The glass disc covering the sealed cylinder was now replaced by cambric and the cylinder put back in the incubator to see if any revival of the larvæ would take place. On the following day (July 24) the contents were turned out and carefully examined. No live insects were found, but 298 dead larvæ (many of them much shrivelled) were counted, while, owing to the difficulty of picking them all out from their tunnels in the matted flour, it is probable that a few escaped observation. The contents of the control cylinder were also turned out and found to contain a large number of living larvæ.

The effect of sealing, in this case, was almost startling in its rapidity, but it must be remembered that, although there was a large air-space, there were also a great many larvæ, which must have produced a large amount of carbon dioxide and used up the oxygen supply very quickly.

The results of the experiment suggest, not only that hermetical sealing should prove efficient in protecting biscuits and other food-products from the ravages of the flour-moth, but also that this method of killing the larvæ, which seems to leave them at first in a beautifully extended condition, might advantageously be applied to many species of animals for museum and laboratory purposes.

EXPERIMENT Q′.

The effect of sealing wheat badly infected with Mites *for one day at 24° to 27° C.*

Grain samples used for our experiments or cultures have usually been incubated for long periods in a moist atmosphere to ascertain whether or not they are insect-free. Two cylinders, A and B, were filled with wheat and covered with cambric. A contained uncleaned No. 1 North Manitoba wheat, as taken from the ship, while B contained similar wheat cleaned ready for milling. Both were placed in the incubator, at 24° to 27° C., on March 8. The contents were examined on April 29, when no insects could be found, but many mites and their eggs were present.

On May 22 both contained large numbers of mites, which were very active. A was sealed at 11.45 a.m., B remaining covered with cambric only. Both were replaced in the incubator. At 10.20 a.m. on the following day there was no sign of movement in A, although the shrivelled bodies of the mites could be seen, while in B the mites were normally active. Thus, in less than 24 hours, hermetical sealing was apparently effective in destroying the mites.

EXPERIMENT R′.

The effect of sealing Mites *for nineteen and a half hours at* 31° *C.*

The mites were taken from a culture of *Calandra granaria.* This culture was very thick with weevils and the wheat was rather mouldy. On May 17 the mites were observed to be migrating in immense numbers through the cambric cover, owing presumably to unfavourable conditions in the cylinder. Approximately equal quantities of the mites, in the form of fine dust, were collected from on top of the cover with a camel-hair brush and placed in two small tubes each of about 2·5 c.c. capacity. One tube, A, was sealed at 4 p.m., the other, B, being covered with cambric as a control. Both were placed in a 75 c.c. test-tube, which had a band of vaseline smeared round the inside near the top to prevent the mites, which could easily pass through the cambric, from escaping into the incubator.

On May 18, at 11.30 a.m., the tubes were examined. A considerable number of the mites had made their way through the cambric of tube B, but had been prevented by the smear of vaseline from escaping from the outer tube. The two small tubes were examined under the microscope. In the sealed tube, A, no sign of life could be seen and the mite-dust had contracted into a solid mass. In the ventilated tube, B, the mites were alive and quite active.

It should be observed that the air-space in the sealed tube was very large relatively to the amount of mite-dust, which occupied not more than about one-tenth of the tube, so that it would appear that the mites must use up the oxygen and produce carbon dioxide at a very rapid rate, a process which may be aided by bacterial action. The mite in question was probably *Tyroglyphus siro.*

EXPERIMENTS WITH TWO SECONDARY GRAIN PESTS, SHOWING THEIR INABILITY TO ATTACK SOUND WHEAT.

By ARTHUR DENDY, D.Sc., F.R.S.

Tribolium castaneum and *Silvanus surinamensis* are two small beetles often met with in large numbers in damaged grain. They are usually regarded as secondary grain pests, feeding upon the débris produced by the attacks of other insects, notably weevils. It seemed desirable to know definitely, however, whether or not they were capable of injuring sound grain, and the following experiments seem to show pretty conclusively that they are not.

A.—*Experiment to determine whether or not* Tribolium castaneum *attacks sound wheat.*

The wheat used was a sample of No. 2 Club Calcutta, supposed to be clean. Two glass jars were taken, of which one was partly filled with whole wheat and the other with the same wheat partially crushed in a mortar. Each jar was infected with 120 living specimens of *Tribolium castaneum*, and placed in a moist incubator kept at a temperature of about 31·5° C. on November 19, 1917.

On December 18 the whole wheat was turned out and examined. Amongst it were found 103 dead Tribolium, 17 living Tribolium, and one living *Calandra oryzæ*, the last-named probably derived from the wheat sample, which was not quite free from infection. Another Calandra had been removed on November 21. The 17 living Tribolium and the wheat were replaced in the incubator. On January 17, 1918, they were again turned out and only one living Tribolium was found. No larvæ or pupæ were found on either occasion.

The beetles in the jar of crushed wheat behaved in a very different manner. Already on December 7 fairly numerous larvæ were present in the jar, and on December 18 pupæ were observed. By December 24 the jar was swarming with adults, larvæ and pupæ. On January 17, 1918, the contents were turned out and carefully examined; 419 living adults were found, 12 dead adults, 23 living larvæ of various sizes, and no pupæ. In addition to these, three adults had been removed on December 4 and 23 on December 7.

It thus appears that in about two months the beetles in the jar of crushed wheat had increased nearly fourfold, while those in the jar of whole wheat had not increased at all, but, on the contrary, had all died except one. The fact that one remained alive is doubtless to be attributed to the circumstance that the wheat was in reality slightly damaged, for, as we have already seen, two weevils were found in it, and on one occasion about a dozen Tribolium and one of the weevils were seen clustered around what appeared to be the remains of a much-gnawed, damaged grain, upon which they were doubtless feeding. On another occasion also, one of the Tribolium appeared to be feeding upon a damaged grain.

From this experiment it is safe to conclude that *Tribolium castaneum* is only a secondary wheat pest, incapable of damaging sound grain.

During the course of this experiment the adult beetles in the jar of crushed wheat were observed to be heavily infected with mites. Samples of the insects thus infected were sent to Prof. Newstead for investigation.*

B.—*Experiment to determine whether or not* Silvanus surinamensis *attacks sound wheat.*

A culture of the saw-toothed grain beetle, *Silvanus surinamensis*, was started on November 19, 1917, with about 20 individuals, and flourished exceedingly. The wheat used was No. 2 Club Calcutta, bruised in a mortar, and the culture was kept in a moist incubator at a temperature of about 31·5° C.

On December 4 numerous larvæ were observed, and between December 12 and December 14 a perfect insect emerged from a pupa in a sub-culture, making the total period for the life-cycle not more than 25 days. On December 18 the original tube contained numerous larvæ, pupæ and imagines.

On December 21 sub-cultures were taken for the experiment about to be described. For this purpose two 4-inch test-tubes were employed, with cambric tied over the mouths. In one of these were placed 50 carefully selected, uninjured grains of wheat (No. 2 Club Calcutta), each grain being examined with a lens. Twenty adult Silvanus were added. In the other, 50 grains of the same wheat, crushed in a mortar, were placed, together with 20 adult Silvanus. Both were placed in a moist incubator, maintained at a temperature of about 31·5° C.

On January 17 the contents of both tubes were turned out and examined. In the tube with whole wheat only the original 20 insects were found, all dead. No larvæ or pupæ were found, and the wheat showed no signs of injury. In the tube with the crushed wheat 24 living adults were found and no dead ones; there were also a considerable number of larvæ and pupæ.

From this experiment it may be concluded that *Silvanus surinamensis* is only a secondary pest in wheat and does not attack sound grain.

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* *See* Report No. 2, by Prof. Newstead and Miss Duvall, p. 19.

OBSERVATIONS ON THE ATTRACTION OF CERTAIN GRAIN BEETLES, ESPECIALLY WEEVILS, BY WATER.

BY ARTHUR DENDY, D.Sc., F.R.S.

These experiments were inaugurated by the following casual observations. Three large samples of badly infected wheat were kept in the laboratory at ordinary room temperature in large glass vessels, two of them (Nos. 2A and 3A) covered with paper, and the other (No. 1A) with a sheet of glass.

On November 2, 1917, a glass beaker, partly filled with water, was placed in each sample, plunged in the wheat, for the purpose of keeping the atmosphere moist. On the next day, after rather more than 24 hours, the beaker in sample 1A had caught 270 *Silvanus surinamensis* and 105 *Calandra granaria*; that in 2A had caught 533 *Calandra oryzæ*; that in 3A had caught 352 *Calandra oryzæ.* All of these insects had been unable to get out of the water into which they had fallen. Stimulated by this accidental result, I made the following experiments:—

On November 3 I placed two beakers side by side, plunged in the wheat to within about an inch of the rim, in Sample 2A. One of the beakers was half filled with water and the other dry. On November 6 the dry beaker contained only 7 *Calandra oryzæ*, while the one with water had caught 692.

A beaker half full of water was also placed, on November 3, in each of Samples 1A and 3A, and on November 6 these were found to have caught, respectively, 23 *Calandra granaria* with 75 *Silvanus surinamensis*, and 1,303 *Calandra oryzæ* with 2 *Tribolium castaneum.*

As the sample containing the *Calandra granaria* did not appear to be appreciably less heavily infected than those containing the *Calandra oryzæ*, it appeared as if the latter species was much more readily attracted by the water than the former. To test this matter further I made the following experiments:—

On November 24 I took a glass cylinder, about 200 mm. high by 71 mm. inside diameter, and filled it about half full of supposed clean wheat (No. 2 Club Calcutta), together with 116 specimens of *Calandra oryzæ* and the same number of *Calandra granaria.* In the middle of the wheat I plunged a 4-inch test-tube partly filled with water and buried in the wheat to within about 10 mm. of the rim. The cylinder was covered with muslin and kept at room temperature. On November 26 the test-tube was found to have caught 13 weevils, all of them *Calandra oryzæ.* This result certainly seemed to indicate that *Calandra oryzæ* is more readily attracted by water than *Calandra granaria*, and to support the conclusions derived from the previous experiments. It was possible, however, that *Calandra granaria* might have greater facilities for escaping from the test-tube, or beaker, without actually falling into the water.

To test this possibility, I again took the same cylinder of wheat, with the weevils remaining in it (presumably 116 *Calandra granaria* and 103 *Calandra oryzæ*) and plunged in it two test-tubes of the same size as before. In the lower half of one of the tubes I placed two pieces of damp sponge, and in the other two similar pieces of dry sponge, and again kept them at room temperature. This was at 4 p.m. The next morning, at 11 a.m., the tube with dry sponge was found to contain one *Calandra granaria* only. That with the damp sponge, on the other hand, had caught 37 *Calandra granaria* and 32 *Calandra oryzæ*. This seemed to show that the two species were attracted by moisture in almost equal numbers.

On November 27 the apparatus was arranged as for the previous experiment, with the addition of 13 *Calandra oryzæ* to equalize the numbers of the two species (presumably, if none had died, 116 of each). I also placed 40 grains of clean wheat beneath the sponge at the bottom of each tube in order that the weevils might be induced to remain and feed. The tubes were left for 16 days (till December 13) at room temperature and then examined. In the dry sponge tube only six weevils were found and these were all *Calandra granaria*; only one of the six was alive, as tested by incubation, and not one of the 40 grains of wheat showed signs of attack. In the damp sponge tube, although the sponge had apparently dried up, I found 39 *Calandra oryzæ*, of which only three proved to be dead, and 37 *Calandra granaria*, of which only one proved to be dead, and 14 of the grains of wheat had been more or less extensively gnawed.

These experiments serve to confirm the general opinion that both species of weevils are attracted by moisture. They also indicate that there is really no difference between them in this respect, but that when water is actually present in sufficient quantity at the bottom of the tube or beaker, *Calandra oryzæ* is very much more likely to be caught in it than *Calandra granaria*. This is remarkable, in view of the fact that *Calandra oryzæ* possesses well-developed wings (though I have hardly ever seen it make use of them), while *Calandra granaria* has none. It seems probable that *Calandra granaria* is more sure-footed than *Calandra oryzæ*, and is able to climb back up the side of the vessel containing the water, while *Calandra oryzæ* much more frequently slips in and is caught.

It is possible that, under certain circumstances, water-traps might prove effective in catching *Calandra oryzæ* in large numbers, and if damp rags or sponge were used both species might be trapped, owing to their love of moisture.

In going through the literature of the subject, I find that Miss Ormerod long ago suggested the use of water-traps for catching weevils in granaries ("The Entomologist," vol. xii, 1879, p. 207).

ROYAL SOCIETY.

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CONTENTS.

1. Report on various Gaseous Reagents, by J. S. Edkins, M.A., M.B., D.Sc., and Nora Tweedy, M.Sc.

2. On "Webbing" in Stored Grain, by Prof. A. Dendy, F.R.S., and H. D. Elkington, B.Sc., F.I.C.

3. On the Occurrence of Live Insects in Tins supposed to be Hermetically Sealed, by Prof. A. Dendy, F.R.S.

REPORT ON THE EFFECT OF VARIOUS GASEOUS REAGENTS UPON THE FLOUR MOTH (EPHESTIA KÜHNIELLA) AND OTHER PESTS FOUND IN FLOUR.

By J. S. EDKINS, M.A., M.B., D.Sc.,
and NORA TWEEDY, M.Sc.

The other pests recognized were—

1. *Tribolium castaneum* (Herbst) (large numbers).
2. *Tribolium confusum* (rare).
3. *Gnathocerus cornutus* (rare).
4. *Laemophloeus pusillus* (rare).
5. *Tenebrioides mauretanica* (not common).

In the experiments attention was chiefly directed to Ephestia.

In the experiments the contaminated flour was introduced into a large aspirator of about 17·5 litres capacity, either in small quantity to avoid the difficulty of penetration of the gas or in large quantities to permit observations to be made upon the degree of penetration occurring. The gas was either generated within the aspirator or directly introduced from without.

FORMALDEHYDE.

Formalin solution was heated by an electric current within the aspirator. A fairly high concentration was obtained (the exact concentration was not estimated) and the flour was left exposed to the vapour for 24 hours. There was no immediate effect. The beetles did not react at all. In 24 hours exposed larvæ were apparently killed, but those at a short depth beneath the surface were unaffected, suggesting that the penetrative powers of the formaldehyde were small. The few experiments made with formaldehyde did not indicate sufficient promise of success to justify their continuance.

SULPHUR DIOXIDE.

In our experiments with sulphur dioxide we quite early appreciated the fact that the flour we were testing was generating carbonic acid gas in considerable quantities. As this production vitiated some of our earlier analyses of the concentration of the SO_2 at different intervals of time we made a few experiments to ascertain at what rate CO_2 was produced. A sample experiment is here recorded.

Estimation of CO_2 produced in 17 hours by about Two Litres of Cobweb Flour.

The sample of flour was not dried, it contained large quantities of Ephestia at different stages and other pests. It was enclosed in an aspirator of 17·5 litres capacity.

Estimation of CO_2 within half an hour after enclosing flour gave 0·3 per cent. in the enclosed air.

After 17 hours the CO_2 was again estimated and gave 2·8 per cent. in the air.

We regard this CO_2 production as due to the different forms of insect life in part and also to the presence of the micro-organisms in the flour.

We made several experiments in which we estimated the proportions both of CO_2 and SO_2 at different intervals. A sample experiment is cited:—

> About two litres of contaminated flour were placed in aspirator of 17·5 litres capacity, and SO_2 was introduced to give a theoretical percentage of about 10.
>
> In 20 hours, estimation of the SO_2 gave 0·9 per cent.; estimation of the CO_2 gave 4·25 per cent.
>
> In 72 hours, estimation of the SO_2 gave 0·6 per cent.; estimation of the CO_2 gave 4·6 per cent.; estimation of the oxygen 15·95 per cent.
>
> There was no sign of life in the pests after about two hours. At the end of the 72 hours' period everything was certainly dead.

This experiment shows that the SO_2 rapidly disappears, being absorbed by the moisture of the flour; further, that after a time the CO_2 ceases to increase, presumably because the agents of production are killed. We consider that the SO_2 is able to effect its destructive action either when it is dissolved in the moisture, or before its concentration is greatly reduced by absorption, i.e., within the first hour or two of introduction.

In further experiments, we dried the flour in the aspirator by exposure to a current of air before introducing the gas:—

> *Effect of SO_2 2 per cent. upon dried flour.*—Method as before. After 18 hours no signs of life was seen.
>
> *Effect of SO_2 1 per cent. upon dried flour.*—Even as low a percentage as 1 with dry flour appears to suspend all signs of life in 10 minutes; there is no movement, and the beetles are seen to be lying on their backs, the Ephestia larvæ have dropped off the sides of the vessel upon which they have been climbing. After 18 hours everything is dead.
>
> *Effect of SO_2 0·5 per cent. upon dried flour.*—It was possible to watch the gradual effect of the gas by observing the larvæ one by one falling off the sides of the aspirator. One grub stuck to the glass for three quarters of an hour, some signs of life were still observable after 2 hours, in 3¾ hours all appearance of life had vanished.

Our conclusions are that exposure to 1 per cent. of SO_2 for half an hour will kill all stages of Ephestia.

An important incidental point to which we gave attention was whether the effect of the SO_2 was to alter in any degree the dough-making properties of the flour. Some of the treated flour that we sent to Messrs. Robinson, of Greenwich, was condemned by them as valueless for breadmaking. We were informed by them that treatment of grain by sulphur destroyed its value. We made some experiments to see what effect was brought about by the SO_2. Flour left all night exposed to the gas (2 per cent.) was obviously bleached. The dough was remarkably sticky, and the gluten, when separated, sticky and slimy. It very obviously had lost its ordinary properties. The effect was less marked with 1 per cent. SO_2, but was observable even with 0·5 per cent.

It seems then that if the very effective sulphur dioxide treatment were adopted, it would necessitate the temporary cessation of the milling. Any flour in circulation during the treatment would be useless for bread-making.

AMMONIA.

Using 5 per cent. ammonia we found that the larvæ and beetles were quite unaffected. The only change that we could appreciate was that they were apparently brought to the surface of the flour.

ETHER.

Ether was sprayed by an atomizer into the aspirator. In a few minutes all animals became apparently lifeless. Probably anæsthetised.

ALCOHOL.

Spraying methylated spirit by an atomizer did not suspend life in half an hour. On opening up the next day, however, no sign of life could be detected.

ETHER AND ALCOHOL EXTRACTS OF "KEATING."

We could not satisfy ourselves that these extracts had any power of killing that was not possessed by the solvents. The Keating was freshly opened and presumably reliable.

OZONE.

We had evidence put before us that dry air-carrying ozone might afford the ideal ventilating medium for use in mills either as a general ventilating medium or restricted to the flour conduits as far as possible.*

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* We understand that the supply of ozone is an essential part of the system of ventilation introduced by the "Ozonair" Company.

For the purpose of testing the effect of ozone we arranged the following installation :—

Description of Apparatus (*see* diagram).—An electric blower propelled a current of air first through a tower containing pumice and sulphuric acid to dry the air. The air then passed through soda-lime to remove any CO_2. Then the current was split into two circuits. In the "A" circuit it passed through the ozonizer, thence through a cooling vessel, thence through a trial aspirator, in which was clean flour and in which were suspended strips of metal at times in order to see the effect of the ozone upon different kinds of metal. Thence the current passed through the "A" aspirator in which was the contaminated flour. Then it was led through two traps of a solution of potassium iodide to estimate the contained ozone. Finally, it passed through a meter, and the rate of the current could be regulated by a clamp on the tube leading to the first aspirator. Rubber was necessarily discarded in the connections, and the joints were made of plasticine. The "B" circuit was similar, except that there was no ozonizer and no traps. The "B" circuit, therefore, afforded the same conditions of coolness and dryness as the experimental circuit "A." The controlling clamps were adjusted so that currents of air of the same quantity passed by either circuit. "B" therefore acted as a control on the effect of the ozone in "A."

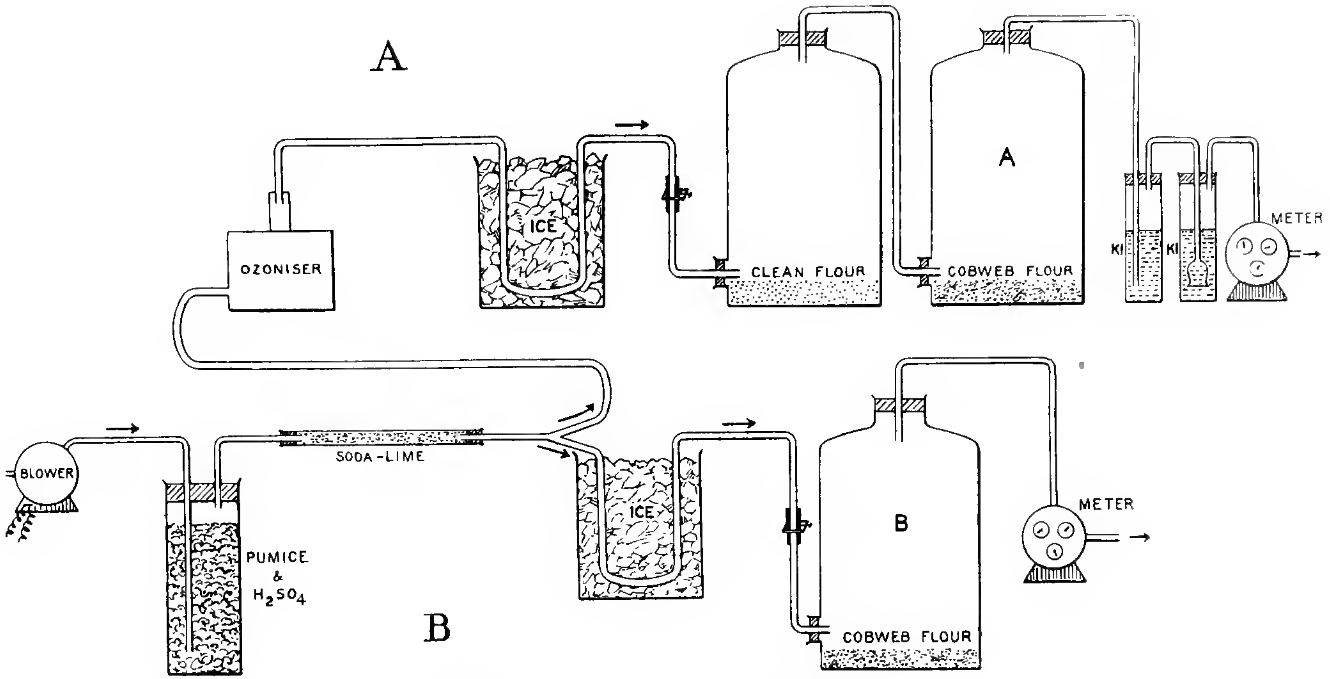
By the employment of this apparatus samples of infected flour were exposed to different concentrations of ozone in dry air. The effect of the ozone was carefully controlled. The treated flour was examined from time to time during any experiment.

Our experiments were directed to ascertaining :—

1. The influence of intermittent high concentration of ozone on the flour in bulk.
2. The influence of comparatively low concentration of ozone, *continuously* applied, on the flour in bulk.
3. The influence of intermittent medium concentration on the moth alone.

(1) *Intermittent High Concentration.*

In a typical example of this class the experiment lasted from March 23, 3.0 p.m., to April 3 (morning). The whole duration may be taken as 280 hours. At intervals during this period, there were run through the two circuits 3,620 litres of air, that through the treatment circuit being highly ozonized. During the ventilating periods the ozone concentration averaged 550 parts per million through the treatment circuit. The actual number of hours occupied in ventilating was 15 (and 35 minutes). The apparatus was closed at the end of each ventilating period so that the exposure to ozone was longer than the actual time of ventilating. If the total quantity of ozone had been spread evenly over the whole time the concentration would have amounted to about 30 parts per million.



ARRANGEMENT OF APPARATUS IN OZONE EXPERIMENTS.

The conditions at the end of the experiment were as follows:—

In the control jar there was apparently unaffected cobweb flour. Moth had appeared from time to time during the experiment and copulation had been observed. Larvæ frequently ascended to the bung and cocooned there.

In the treatment jar there were still living Ephestia larvæ, which moved about upon exposure. Both living and apparently dead Tribolium larvæ were visible, also living and dead beetles of same class. Three Tenebrioides larvæ and one beetle were found alive. No Ephestia moth were observed at any time during the experiment in the treatment jar. It may have been that one effect of the ozone was to inhibit the transformations even though the animals were not destroyed

(2) *Continuous Exposure to Low Concentration.*

Though we describe this as continuous exposure we must state that the exposure was only actually continuous during the first four days. After this time only day-treatment was possible and the flour was exposed to a double strength concentration for about 9 or 10 hours in the daytime and closed up at night, when of course the concentration gradually fell. The main experiment lasted twenty-six days. Brief pauses were necessary for renewing the test solutions but of too short a length to cause any appreciable alteration of concentration. To give a correct idea of the character of this experiment we set it out in some detail:—

April 17, occupied in various adjustments involving intermittent ventilation, till

6.30 p.m. Started experiment, ventilating at rate of 2·5 litres per minute. This corresponded to renewal of air of jar once in 7 minutes.

April 18, 5.0 a.m. Renewed potassium iodide solution; 1,320 litres of air recorded; estimation of iodide gave ozone equalling 30 in a million.

12.15 p.m. Renewed test solution; 2,290 litres air recorded; ozone, 35 per million.

6.45 p.m. Renewed test solution; 3,077 litres air recorded; ozone, 37 per million.

April 19, 2.30 a.m. As test solution seemed to be changing rather slowly, increased concentration of ozone. Discovered slight leak.

.9.45 a.m. Renewed test solution; 4,016 litres air recorded ozone 15 per million. Made some readjustments for greater concentration.

3.30 p.m. Observed flour to have become whiter in treatment jar. A moth seen earlier in control jar now disappeared. Larvæ moving about in both jars.

April 19, 6.0 p.m. Renewed test solution; 4,907 litres air recorded; ozone, 26·6 per million.

April 20, 2.30 a.m. Renewed test solution; 5,940 litres air recorded; ozone, 20·8 per million.

9.45 a.m. Renewed test solution; 6,887 litres air recorded; ozone, 29 per million.

5.30 p.m. Renewed test solution; 7,869 litres air recorded; ozone, 28 per million.

8.30 p.m. Stopped and closed down for night; renewed test solution; ozone, 39·7 per million.

April 21, 10.45 a.m. Restarted.

5.0 p.m. Observed flour. More larvæ visible in treatment jar than in control. 18 counted. Some seem torpid, but some Ephestia larvæ are moving with much vigour. One Tenebrioides larva seen slowly moving. Beetles are lively. A moth seen earlier in afternoon has now disappeared. In control jar a few larvæ are seen but are much more leisurely in movement. It appears as though the ozone had a stimulating effect upon movement.

6.0 p.m. Stopped and closed down for night. 9,064 litres air recorded; ozone, 39·5 per million. Left closed down till April 23.

April 23, 11.25 a.m. Restarted.

5.0. p.m. Renewed test solution; 9,626 litres air recorded; ozone, 47·4 per million.

8.15 p.m. Stopped and closed down for night. Renewed test solution; 9,901 litres air recorded; ozone, 49·7 per million.

April 24, 10.45 a.m. Restarted.

2.30 p.m. Observed flour. A moth is seen alive in treatment jar; larvæ in both jars; more beetles visible in treatment jar than in control.

3.0 p.m. Renewed test solution; 10,397 litres air recorded; ozone, 50·5 per million.

8.0 p.m. Stopped for night and closed down. 10,864 litres air recorded; ozone, 52·8 per million.

April 25, 10.30 a.m. Restarted.

2.30 p.m. Renewed test solution; 11,382 litres air recorded; ozone, 46·4 per million.

6.10 p.m. Stopped and closed down for night. 11,744 litres air recorded; ozone, 57·5 per million.

April 26, 10.45 a.m. Restarted.

12.45 p.m. Renewed test solution; 12,005 litres air recorded; ozone, 37·3 per million.

6.45 p.m. Stopped and closed down for night. 12,687 litres air recorded; ozone, 42·1 per million.

April 27, 11.15 a.m. Restarted.
3.15 p.m. Renewed test solution; 13,182 litres air recorded; ozone, 56·7 per million.
7.40 p.m. Stopped and closed down for night. 13,661 litres air recorded; ozone, 61·2 per million.

April 28, 9.55 a.m. Restarted.
2.0 p.m. Renewed test solution; 14,102 litres air recorded; ozone, 70·8 per million.
5.45 p.m. Stopped and closed down for night. 14,471 litres air recorded; ozone, 61·9 per million.

April 30, and May 1. Suspended ventilation temporarily. Examined flour from each jar. Took 37 grms. from each. Control flour contained very few dead animals. Treatment jar contained many living animals, but a rather larger proportion of dead than control jar.
3.0 p.m. Restarted.
6.0 p.m. Stopped and closed down for night. 14,648 litres of air recorded; ozone, 53·7 per million.

May 2, 10.0 a.m. Restarted.
3.20 p.m. Renewed test solution; 14,969 litres air recorded; ozone, 64·5 per million.
6.15 p.m. Stopped and closed down for night. 15,209 litres air recorded; ozone, 58·3 per million.

May 3, 10.0 a.m. Restarted.
2.0 p.m. Renewed test solution; 15,572 litres air recorded; ozone, 90·9 per million.
6.0 p.m. Stopped and closed down for night. 15,923 litres air recorded; ozone, 92·3 per million.

May 4, 9.0 a.m. Restarted.
1.45 p.m. Renewed test solution: 16,398 litres air recorded; ozone, 56·4 per million.
6.0 p.m. Stopped and closed down for night. 16,777 litres air recorded; ozone, 77·5 per million.

May 5, 11.30 a.m. Restarted.
6.0 p.m. Stopped and closed down for night. 17,325 litres air recorded; ozone, 71·3 per million.

May 7, 10.0 a.m. Restarted.
5.30 p.m. Stopped and closed down for night. 18,041 litres air recorded; ozone, 65 per million.

May 8, 11.15 a.m. Restarted.
6.0 p.m. Stopped and closed down for night. 18,775 litres air recorded; ozone, 65 per million.

May 9, 11.0 a.m. Restarted.
6.0 p.m. Stopped and closed down for night. 19,427 litres air recorded; ozone, 46 per million.

May 10, 10 a.m. Restarted.

5.15 p.m. Stopped and closed down for night. 19,962 litres air recorded; ozone, 47·5 per million.

May 11, 11.0 a.m. Restarted. Noted that after concentration had got up, beetles previously quiescent became lively, but their movements did not appear purposeful and were apparently of a convulsive order.

6.15 p.m. Stopped and closed down for night. 20,401 litres air recorded; ozone, 92 per million.

May 12, 12.15 p.m. Restarted. Ozone, 75 per million during the day.

6.0 p.m. Concluded experiment. Apparatus closed down till May 14 (26 days from commencement of experiment). 20,810 litres of air had passed.

Examination of Flour.

Treatment Jar.—This contained about 80 grms. of flour, of which 29·5 were examined as carefully as possible.

Animals found alive	15	larval Tribolium.
	7	Tribolium beetles.
	1	(? alive) Ephestia larva.
Total	23	
Animals found apparently dead...	158	larval Tribolium.
	20	larval Ephestia.
	6	larval Tenebrioides.
Total	184	

(There were some broken segments of dead animals and some may have have been missed.)

Control Jar.—This contained about 75 grms., of which 30 grms. were examined as carefully as possible. The sample taken did not contain a large number of animals either alive or dead.

Animals found alive	13	larval Tribolium.
	10	Tribolium beetles.
	7	Ephestia larvæ.
	2	Tenebrioides larvæ.
	1	moth hatched from chrysalis whilst examining.
Total	33	

Animals found apparently dead ...	5 Tribolium beetles. 1 Tenebrioides larva. 2 Tribolium larvæ.
Total	8

Percentage of living animals in treatment jar,	11·1.
„ „ control jar,	80·5.

It is to be observed that dryness accounted for a mortality of 20 per cent., dryness plus ozone for a mortality of 89 per cent.

We decided in the next place to ascertain the effect of the ozone upon the moth alone. We were able to procure fairly large numbers of these by placing the infected flour in a large bin, and tying a damp cloth over the top. The moth, as they hatched out, settled in considerable numbers on the cloth, and by cutting the cloth into two, removing each half carefully, and shaking the same inside the jars, we procured about 30 moth at a time in a perfectly uninjured state. Some other pests were incidently added.

We made several experiments with different concentrations and different exposures (as regards duration).

Effect of Ozone upon Moth.

We found that high concentrations for some 7 or 8 hours, that is over 100 parts of ozone per million, were lethal for moth with two exposures, but not with one. This means that the moth were exposed for about seven hours to the ozonized air, then shut down for 17 hours, and then again exposed, and again shut down for 17 hours. After 48 hours all moth were killed in the treatment jar, but less than 50 per cent. in the control jar (dryness only).

In another experiment, out of 35 in the treatment jar, all were killed but one, and this was moribund. In the control jar out of 38 moth, five were dead after 48 hours.

With respect to other forms of life than moth which were simultaneously introduced, there was noted:—

Larvæ.—Some apparently dead, some certainly alive. One Ephestia larva appears quite normal. No cocooning is visible. One Tenebrioides larva is lying upon its back feebly kicking. There is one string of eggs, and probably a few scattered ones.

All this was in treatment jar.

In the control jar, there were living larvæ and some cocooning. Some of the moth have strings of eggs attached to the abdomen. Many more eggs appear scattered about than in the treatment jar.

We, unfortunately, did not notice when the string of eggs in the treatment jar appeared, but we suspect it must have been quite early.

We desire to call attention to the absence of cocooning, and the fewness of the eggs in the treatment jar as compared with the control jar.

In another experiment with a smaller concentration of ozone the observations were similar but less striking. We think that with a concentration of 50 in a million, in spells of seven hours ventilation with 17 hours shut down, three days' treatment would kill all moth though not the larvæ. The moth appear more susceptible than the beetles. Imago stage appears more susceptible than larval.

General Remarks upon Ozone Treatment.

Ozone appears to prevent development of Ephestia in flour in concentrations of about 50 in a million, if delivered in dry air, for the following reasons:—

1. It tends to destroy the moth, though not to kill the larvæ in any appreciable degree.
2. It appears to inhibit the transformations. Though the animals may not be destroyed they seem to be deprived of their normal powers of continuing development. (Absence of cocooning and egg-laying.)
3. The presence of ozone in the air in a concentration of more than 5 in a million would be injurious to human life. It could therefore be used in closed circuits in perhaps 50 in a million, but not in the air to be breathed by man.

ON THE PHENOMENON KNOWN AS "WEBBING" IN STORED GRAIN.

By ARTHUR DENDY, D.Sc., F.R.S.,
Professor of Zoology in the University of London, and

H. D. ELKINGTON, B.Sc., F.I.C.

The remarkable phenomenon known to the trade as "webbing" was mentioned to one of us by Mr. Webb, Vice-Chairman of the Landed Grain Committee of the Royal Commission on Wheat Supplies, at an interview at Holland House on July 10, 1918. It appeared from Mr. Webb's statements that from time to time a kind of web makes its appearance, which may completely cover large heaps of grain stored on granary "floors." The appearance of this web is welcomed by experts in the trade as a sign that the wheat beneath it is in good condition, and one inspector informed us on a subsequent occasion that when he came across a heap covered with webbing he never considered it necessary to investigate it any further but took it for granted that the wheat underneath could be safely left without attention.

The phenomenon does not appear to be a very common one, and we have only come across one reference bearing upon it in the literature which we have examined. Mr. Hooper, in a Report on Damage by Wheat Weevil, published as Appendix N to F. Noël-Paton's "Indian Wheat and Grain Elevators," observes "it has also been shown that worms and moths secreting a web in the wheat are a source of destruction to the Calandras as they become entangled in the meshes and die in large numbers when these are present."

Mr. Webb very kindly offered to let us know as soon as a case of webbing came under his notice, and on September 24 we had the opportunity of making a thorough investigation of the phenomenon at a warehouse belonging to the Port of London Authority at the Surrey Commercial Docks, under the guidance of the Landed Grain Committee's Superintendent, Mr. Falby, and other gentlemen connected with the docks and warehouses.

The grain in question was piled in large heaps, some four or five feet in height, on the floor of the warehouse. It was Canadian wheat of the variety known as No. 1 North Manitoba, and had been landed in bulk from the s.s. "Kumeric" in the preceding May.* The granary was well ventilated by open windows but except near the windows it was very feebly lighted.

We were told that the web had been forming for five weeks. At the time of our visit it was still very thin on the lighter side of the "floor" but stronger in the darker parts, where it formed a continuous sheet over the heaps, extending over many square yards without a break and covering the adjacent woodwork as well as the grain itself. It had the appearance of a very dense cobweb and reflected the light with a silvery sheen like that of a snail-track. The web possessed very considerable strength and coherence and could be stripped off and rolled up with the greatest ease, though a good many grains adhered to its under surface in the process. It appeared to be entirely confined to the surface layers of the grain. On the adjacent woodwork it was so thick as to resemble thin kid leather.

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* The moisture content of a sample taken on October 4 from a depth of 18 inches in the heap was determined on October 14 and found to be 13·2 per cent.

The cause of this phenomenon was at once obvious, for the surface of the grain and the adjacent woodwork were swarming with countless thousands of caterpillars ("maggots"), which proved to be the larvæ of a very common and destructive moth—*Ephestia elutella*. Specimens of the adult moth were also caught in the warehouse, but they did not occur in large numbers. The identification was made for us by Mr. Hartley Durrant of the Natural History Museum, from specimens bred by us from the larvæ.

It was evident that the web was the result of the confused wanderings of thousands of larvæ over the surface of the grain, each trailing behind it a thread of silk. When full-fed they migrate from the grain to the adjacent woodwork, where some of them doubtless pass the winter as resting larvæ (followed by pupæ) beneath tent-like cocoons. A few moths, however, emerged in the laboratory at King's College in October and November, some at room temperature and others at a temperature of about 79° to 81° F. and, as already stated, some were actually found in the granary itself. We were informed that the web only forms during the summer and there can be little doubt that the larvæ hatch out from eggs laid by the moths earlier in the year. The phenomenon of "webbing" is by no means confined to wheat, for it is well known that the larvæ of *Ephestia elutella* will attack almost anything. On the other hand this is not the only species which is capable of producing such a web, and the phenomenon is very probably due to different insects in different cases. *Ephestia elutella*, however, appears to be so widespread and common in this country that it seems likely that it is usually the responsible agent.

The next problem that calls for solution in this connection is the question of the amount of damage done to the wheat by the larvæ. It was obvious from the most casual inspection that not only do these insects foul the grain to a considerable extent, by their excrement, but that they actually feed upon it, as might naturally be expected. A large proportion of the grains at the surface of the wheat were found to have been attacked in a very characteristic manner, the germ or embryo being eaten clean out, while the remainder of the grain was seldom, if ever, affected, unless perhaps by continued gnawing immediately around the extirpated germ. This method of attack is also characteristic of the Cadelle Beetle (*Tenebroides mauritanicus*), concerning which Dean* informs us that "both the larvæ and the adults also feed upon grain, going from kernel to kernel, devouring the embryo, and thus destroying more seeds for germinating purposes than they consume." The larvæ of *Ephestia elutella* attack small, shrivelled grains as well as large, plump ones and their ravages are probably limited only by the degree of hardness of the material attacked.

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* "Mill and Stored-Grain Insects," p. 207 (Kansas State Agricultural College. Agricultural Experiment Station, Bulletin No. 189, 1913).

On October 4 the warehouse was again visited for the purpose of collecting samples of the grain from various depths in the heap and of obtaining a large supply of the larvæ for breeding purposes. On this occasion the larvæ were found to be swarming on the woodwork in proximity to the grain in very large numbers. Samples of grain were collected from four levels: (1) from the surface, immediately under the webbing, (2) at a depth of six inches, (3) at a depth of one foot, (4) at a depth of 18 inches. The two latter samples were taken by means of a "spear," which was plunged in the wheat in a slanting direction to the desired depth. Owing to illness and pressure of other work these samples were not analyzed till about the end of January and the beginning of February, 1919, when the following results were obtained:—

Sample No. 1.—Dry but dirty, with an offensive smell, webby, with much fæcal matter and some dead larvæ, which had become more or less dry and black. Fifty grammes of the well-mixed sample were weighed out and sorted into

(*a*) Unattacked whole grains, which numbered 1,033 and weighed 28·44 grammes.

(*b*) Attacked but otherwise whole grains, which numbered 714 and weighed 18·06 grammes.

(*c*) Broken grains, foreign seeds, &c., which weighed 2·82 grammes.

(*d*) Fæcal matter and other débris derived from larvæ, including about 20 dead larvæ (or fragments thereof), weighing together 0·38 grammes.

Considering only the unbroken grains it appears that 40·87 per cent had been attacked by larvæ

Sample No. 2.—Dry and fairly clean, with only a slight smell. Fifty grammes, weighed and sorted out as before, gave

(*a*) Unattacked whole grains 1,079, weighing 32·74 grammes.

(*b*) Attacked but otherwise whole grains 576, weighing 15·3 grammes.

(*c*) Broken grains, foreign seeds, &c., weighing 1·81 grammes.

(*d*) Fæcal matter and other débris derived from larvæ, weighing 0·08 grammes.

The percentage of attacked grains in this case is 34·8.

Sample No. 3.—Grain dry, with very little smell and no fæcal matter. Fifty grammes, weighed and sorted out as before, gave

(*a*) Unattacked whole grains 1,579, weighing 46·86 grammes.
(*b*) Attacked but otherwise whole grains 35, weighing 0·95 grammes.
(*c*) Broken grains, foreign seeds, &c., 2·06 grammes.
Percentage of attacked grains 2·16.

Sample No. 4.—Dry and clean, with slight smell. Fifty grammes, weighed and sorted out as before, gave

(*a*) Unattacked whole grains 1,559, weighing 47·02 grammes.
(*b*) Attacked but otherwise whole grains 49, weighing 1·41 grammes.
(*c*) Broken grains, foreign seeds, &c., 1·31 grammes.
Percentage of attacked grains 3·04.

It is evident from these analyses that the damage done by the larvæ is not very serious and takes place almost entirely within 12 inches of the surface of the heap. Though a large proportion of the grains had been attacked in the more superficial layers it must be remembered that even the attacked grains had been only slightly injured from the point of view of their value as human food, though, of course, rendered useless for seed purposes. A more serious result is probably the fouling of the grain by fæcal products and other débris due to the larvæ, but these, no doubt, would be removed in the ordinary cleaning processes to which the wheat is subjected.

There can be no doubt, however, that *Ephestia elutella* must be reckoned as a grain-pest, even if not as a serious one. Whether any good effect of the web on the grain can compensate for the slight amount of damage done (which, of course, might be more serious in other cases) is a difficult question. It seems by no means unlikely that it may, as suggested by Hooper, serve to destroy weevils by entangling them, and indeed we have some very slight evidence to this effect ourselves. A more serious consideration arises from the probability of the affected grain serving as a breeding ground whence the moth might spread to other stores in the neighbourhood, for, as already indicated, the larvæ of this insect feed upon a great variety of food products, many of which would probably be much more seriously damaged than the grain itself. We have, therefore, no hesitation in recommending that it should be exterminated as completely as possible, and other means adopted for maintaining the wheat in a good condition and free from weevils.

In conclusion we wish to express our indebtedness to Mr. Webb, Vice-Chairman of the Landed Grain Committee of the Royal Commission on Wheat Supplies, Mr. Falby, Superintendent, Mr. Ellison, head of the Grain Department, Surrey Commercial Docks, Mr. Fair and other gentlemen connected with the docks and warehouses, for their great kindness and courtesy in facilitating this investigation by personal attention and valuable information.

NOTE ON THE OCCURRENCE OF LIVE INSECTS IN TINS SUPPOSED TO BE HERMETICALLY SEALED.

By ARTHUR DENDY, D.Sc., F.R.S.,
Professor of Zoology in the University of London.

In the second part of the Report on the Effect of Air-tight Storage upon Grain Insects,* attention was called to the apparent failure of the method of packing in hermetically sealed tins as applied to army biscuits, and reference was made to the work† of Mr. Hartley Durrant and Colonel Beveridge on this subject, in which it appears to be assumed that tins inspected by experts and pronounced to be intact may be regarded as air-tight. We ventured to express the doubt whether, in really hermetically sealed tins, any serious damage from insects could arise, and suggested that further investigation should be undertaken by the army authorities.

I have lately had the opportunity of investigating this question personally, and my observations fully confirm the opinion at which we had already arrived as the result of our experiments in sealing up insects in air-tight jars.

In October last an officer from an Army Supply Reserve Depôt near London brought me an unopened 25-lb. canister of army biscuits, specially selected because two of the seams were split, so that, although considered as "intact" owing to the fact that the lid had not been opened, it was far from being hermetically sealed. In fact there appears to be no guarantee whatever that a tin pronounced intact by an inspecting authority is really air-tight. Such tins are liable to become leaky from rough handling or from punctures made by nails when they are enclosed in wooden cases, even if air-tight when first soldered up.

Later on, on December 4, the same officer was good enough to bring me some much more interesting examples, consisting of six 1-lb. tins of pearl barley, supposed to have been hermetically sealed since October, 1914, the date being stamped on the tins, which seemed to be very well made and carefully soldered.

It appeared, however, that a number of tins of the same lot had been opened recently and found to be infected with weevils, and that the whole lot had been condemned on that account. One of the opened tins was included in the six submitted to me for examination and was found to contain live specimens of *Calandra granaria.* In fact I found amongst the barley 16 live weevils and 138 dead ones, but there was no means of ascertaining how many had escaped since the tin was opened.

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* Report of the Grain Pests (War) Committee, No. 3.

† Report on the Temperature reached in Army Biscuits during Baking, especially with regard to the Destruction of the imported Flour-moth, ***Ephestia kühniella Zeller.*** Reprinted with Additions. British Museum (Natural History), 1918.

The five "intact" tins were then tested for leakage by plunging in hot water. Four of them showed escape of air to varying extents. One appeared to be really air-tight and showed no escape. This was opened at once and found to be entirely free from live insects, though two dead specimens of *Calandra granaria* were discovered on careful examination and sifting.

On December 18 the remaining tins, labelled C—F, were again tested with hot water, opened, and their contents carefully examined, with the following results. (The tins were oblong, with a small round lid soldered on in the middle of one of the flat ends.)

C.—Air escaped pretty freely from the seam round the top and very slightly from the seam round the lid. 45 dead *Calandra granaria* were found and no live ones. The barley was in good condition with very few indications of attack.

D.—Air escaped freely from one small crack in the raised rim around one end. 421 dead *Calandra granaria* were found and 78 live ones. A few were left inside the grains. The barley was dry but much gnawed and with a bad smell.

E.—Air escaped, but not very much, from two points in one of the seams. Two dead *Calandra granaria* were found and no live ones. The barley was in very good condition, not noticeably gnawed.

F.—No leak was found, that which was present when the tin was previously tested having probably rusted up or become plugged with dust from the barley. 11 dead *Calandra granaria* were found and no live ones. The barley was in very good condition, not noticeably gnawed.

It is evident from these observations that a weevily sample of barley had been originally sealed up in the tins, for none of the apertures which I found were anything like large enough to admit of the ingress of the insects, indeed it is doubtful if they could have been detected with the naked eye except by the escape of air under water.

It will be observed that all the tins contained a certain number of dead weevils. Presumably the barley was freed from all adult insects, live or dead, by the usual cleaning method before it was sealed up. We may suppose that in the case of the air-tight tin two weevils emerged from the grains and lived as long as the original air supply sufficed. In three of the other tins also, in spite of the fact that there was a small leak, no live insects were found, though infection was clearly demonstrated by the presence of dead ones. I regard this as a very important fact, because it seems to indicate that a *slight* leak in a granary or silo would probably not have a serious effect upon the contents. Indeed it is obvious that the number of insects which could maintain themselves under such conditions must be proportional to the supply of air.

It will also be noticed that in Tin D the number of dead insects found was much larger than the number of live ones, and, considering that the tins had been sealed up for more than four years, it is surprising at first sight that if any insects at all remained alive there should not have been more. It seems probable that enough air was pumped in and out of the minute aperture by changes of temperature and atmospheric pressure to allow of the continued existence of only a very limited number.

In conclusion I think it may be claimed that the observations here recorded show that the supposed ability of certain insects to remain alive indefinitely in hermetically sealed tins is a complete fallacy. They also demonstrate the vital importance of carefully testing such tins for leakage before they are put into store. In the case of small tins at any rate this can easily be done by the hot-water method. In really air-tight tins no insects can remain alive when once the supply of oxygen originally present has been used up, and it is very unlikely that any serious damage can happen to the contents of the tin in the meantime.

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ON THE PREVENTION OF HEATING IN WHEAT BY MEANS OF AIR-TIGHT STORAGE.

By ARTHUR DENDY, D.Sc., F.R.S., Professor of Zoology in the University of London, and

H. D. ELKINGTON, B.Sc., F.I.C.

In connection with our conclusions [Dendy, 1918, Dendy and Elkington, 1918] as to the efficacy of air-tight storage as a means of avoiding the ravages of destructive insects the question has been raised as to the effect of such treatment upon the wheat, more especially from the point of view of the process known to the trade as "heating." It is well known that when wheat, or any other cereal, is stored by the methods in ordinary use it is necessary to keep a watchful eye upon the temperature of the grain and as soon as it rises to a certain degree to turn it over or run it into a fresh silo in order to cool it. The danger is, of course, emphasized in warm weather and when the grain contains a relatively high percentage of moisture, which may either be present initially, as in English wheat, or may be absorbed from a moist atmosphere. The trade has therefore become accustomed to regard abundant ventilation as a necessary condition of successful storage of grain in bulk, and may very naturally look with suspicion upon any proposal to dispense with ventilation altogether. Nevertheless it is obvious that, inasmuch as the "heating" is due to processes of fermentation which themselves depend upon the presence of oxygen, the total deprivation of oxygen must result in the prevention of heating.

As to the actual occurrence of heating and its effect upon the grain when the latter is stored in bulk in receptacles that are not hermetically sealed we may refer to a paper by J. W. T. Duvel [1909], who records his observations upon 5,550 bushels of shelled corn having a moisture content of 17 to 18 per cent., stored in a 65-foot bin at Baltimore, and left without "running" from February 17–18 to April 27, 1909. At the end of this time heating had progressed at the top of the bin until the corn eight inches below the surface had become hot and sour, with a temperature of 133° F., the initial temperature, when the bin was filled, having been 36° to 40° F. The only marked increase in temperature took place in the 6 or 7 feet of corn at the top of the bin, the temperature 12 feet down being 51° to 56° F. and in the lower part of the bin 39·5° to 41·5° F. These observations clearly suggest that the heating was confined to those parts of the bin to which fresh supplies of air could gain access.

As to the correlation between heating and the moisture content of the grain we may quote first from the work of Duvel and Duval [1913], who made observations on cars loaded with shelled corn and containing on an average about 1,193 bushels. Between April 14 and May 11, 1910, in corn with a moisture content of 16·7 per cent. the temperature rose from 58° to 62° F., with a moisture content of 17·8 per cent. it rose from 54° to 82·5° F., with 18·6 per cent. from 52° to 84° F., but with 19·8 per cent. of moisture it rose from 58° to 139·5° F.

From observations extending over a year Bailey [1917] concluded that hard spring wheat of reasonable plumpness containing less than 14·5 per cent. of water is not likely to heat when stored under normal conditions in a temperate climate, while similar wheat containing 15·5 per cent. or more is practically certain to heat.

Saxby [1917–18] states that foreign wheats with 13·5 per cent. of water will with care and attention keep for long periods in silos, and those with 11 per cent. and under require little or no attention, but moist English wheat with 15 to 19 per cent. (average 17 per cent.) will not keep sound in warm weather for periods of even a few weeks in the best-appointed silos ever made. He suggests that the Government should store wheat by mixing the English of high moisture content with Indian or Australian of low. In 14 days the moisture would adjust itself to about 13·5 per cent. and the wheat could be kept for long periods.

A little more than twelve months ago an important memoir was published by Bailey and Gurjar [1918], who attribute the rise of temperature in stored wheat to the "respiration" of the grain. It appears to us unfortunate that the term "respiration" should have come into use in this connection, for it is obvious that what is really meant is fermentation and not respiration in the strictly physiological sense. The authors conclude that "spontaneous heating in damp grain is occasioned by the biological oxidation of dextrose and similar sugars, chiefly in the germ or embryo of the kernel," and thus find themselves in accord with the results of earlier investigators. They point out that increase of temperature accelerates the rate of "respiration" until 55° C is reached. "As the temperature rises the diastatic action upon starch increases. A point is reached, however, at which the enzyme activity diminishes." They also note that accumulation of carbon dioxide in the respiration chamber decreases the rate of respiration and that respiration is reduced in an oxygen-free atmosphere, the ratio to that occurring in a normal atmosphere being about 1 to 2·5.

It would seem to follow logically from these observations that air-tight storage should at least greatly reduce the danger from heating, but it remained to prove this by direct experiment and for this purpose the investigations described in the present report were undertaken.

In order to avoid, as far as possible, the dissipation of heat when experimenting with only small quantities, we made use of thermos flasks. Approximately equal quantities of wheat (about 400 grams) were placed in each of two flasks, together with a thermometer. One of the flasks was sealed and the other lightly plugged with cotton wool. In both experiments the moisture content of the wheat was artificially raised in order to increase the liability to heating. In the first the flasks were kept in an incubator in order to expedite the heating process, in the second they were kept at room temperature.

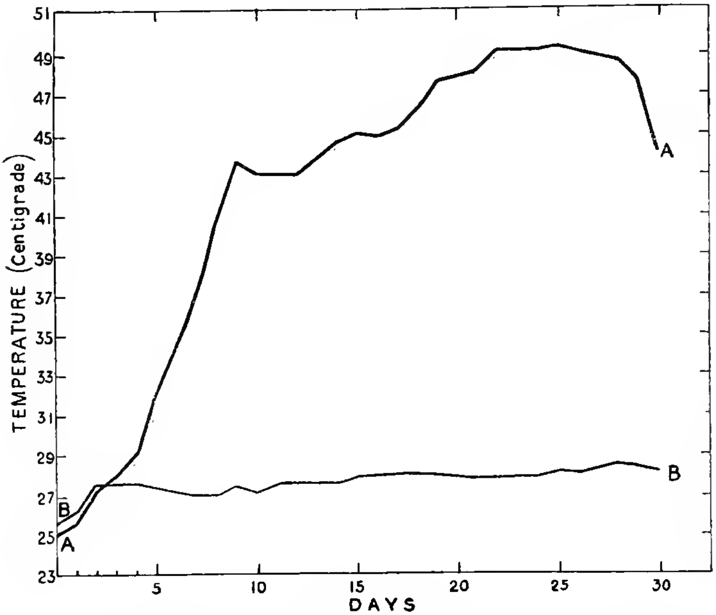
Experiment I.

On February 6, 1919, 800 grammes of mixed English wheat were weighed out and sufficient water added to bring the moisture content up to 20·7 per cent. (by analysis). The damped grain was thoroughly mixed and kept in an incubator at about 30° C. for four days in a closely stoppered bottle to allow the moisture to become evenly distributed through the grain. On February 10 the bottle was removed from the incubator and the stopper blew out, indicating the development of considerable gas pressure. The grain at this time showed no rise in temperature, indeed the temperature appeared to be slightly below that of the incubator, the discrepancy being probably due to the fact that the temperature of the upper part of the incubator, where the incubator thermometer was placed, was actually higher than that of the lower part, in which the grain was. The grain was swollen but showed no sign of germination. It was turned out of the bottle, thoroughly mixed and immediately filled into the two thermos flasks, filling them to within about 1 inch from the top. The flasks were then placed in the same incubator and their temperature recorded daily, except Sundays. The thermometers in the flasks were placed so that the bulb remained in the upper part of the wheat, the lower extremity being about 2½ inches from the top of the flask. The two thermometers did not quite agree in calibration, that in the open flask reading about 0·5° C. higher than the other.

A sample of the moist incubated wheat, taken at the time when the flasks were filled, was tested for carbon dioxide production and it was found that 50 grams of wheat sealed for 24 hours at about 30° C. yielded 0·121 grams of CO_2. It was no doubt the evolution of carbon dioxide that caused the gas-pressure referred to above.

The temperature records of the two flasks are shown in the accompanying curves (Fig. 1, A, B). It will be seen that in the sealed flask (B) the temperature of the wheat, having once risen to that of the incubator, remained almost constant throughout the whole of the period through which the experiment continued. In the ventilated flask (A), on the other hand, the temperature rose rapidly to 43·8° C., then fell slightly* and rose again more slowly to a maximum of 49·4° C., after which the curve began to fall again (Fig. 1).

Fig. 1.



The two flasks were opened on March 13 and the contents examined. In the sealed flask the wheat, though very damp, looked bright and clean, and, with the exception of one or two grains at the bottom of the flask, was quite free from mould or mildew. It was only slightly caked and had a slightly acid smell. The heated wheat in the ventilated flask presented a marked contrast. It had a very musty smell, was badly caked, mouldy on the surface, rotten and black in the lower layers, and very damp. In neither flask was there any sign of germination and a germination test made on wheat from the sealed flask gave no result in nine days, the wheat rapidly going mouldy. The original germination value of the sample was 93 per cent.

Experiment II.

On March 17, 1919, 800 grammes of hard Canadian wheat (No. 1 North Manitoba) was soaked for several hours and then spread out to dry overnight at room temperature. The moisture content on the following day was determined and found to be 34·95 per cent. The damp grain was filled into two thermos flasks as before, the one being lightly plugged with cotton wool and the other hermetically sealed. The two thermometers used this time agreed with one another to within one-fifth of a degree (Centigrade), and as before the bulbs were placed in the upper part of the wheat. The flasks were then packed in cotton wool in a large glass vessel and kept in a cupboard in the laboratory throughout the experiment, which lasted for 76 days. On two occasions, owing to the advent of cold weather, the mercury in the sealed flask sank out of sight (below 12° C.) and remained there for some days, but the interruptions in the curve thus caused (*see* Fig. 2, B) are obviously of no importance, as the temperature of this flask throughout closely followed that of the room (Fig. 2, C) in which the experiment was conducted, there being, as in the first experiment, no indication of heating in the wheat.

---

* Probably more than is shown in the curve, for a Sunday intervened, on which the temperature was not taken, whence the horizontal line in the curve at this point.

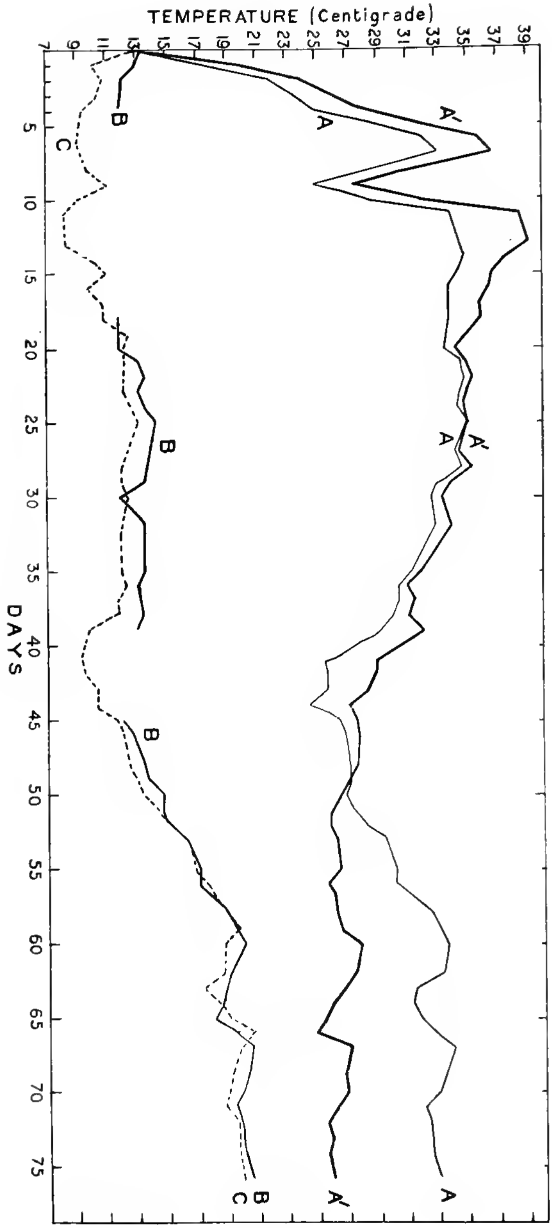
In the ventilated flask, on the other hand (Fig. 2, A), the temperature at once began to shoot up and continued to rise steadily until it reached 33·2° at the end of the 7th day. It then fell abruptly, reaching 24·8° at the end of the 9th day, when it commenced to rise again, attaining a maximum of 35·2° at the end of the 25th day. It then began to fall pretty steadily, reaching 24·6° at the end of the 44th day. At about this time the temperature of the room began to rise considerably, causing a corresponding rise in the temperature of the ventilated flask. If allowance be made for the fluctuations of the room temperature the "heating" curve will be considerably modified, as shewn in Fig. 2, A′. The first and second maxima will both be considerably higher and the fall after the second maximum will be approximately continuous.

On June 2 the two flasks were opened and their contents turned out and examined. In the sealed flask considerable gas pressure had developed. The wheat ran out freely and was not caked or only very slightly so. Though of course very damp and soft it showed no trace of mould or discolouration, but had a fairly strong acid smell and taste and gave a distinctly acid reaction with litmus paper.

In the ventilated flask the grain was very damp, mildewed, caked into an almost solid mass, greatly discoloured, almost black in places, with a very foul ammoniacal smell. In the lower part it was not quite so rotten.

These two experiments demonstrate very conclusively that "heating" of wheat does not take place in hermetically sealed vessels under the conditions given, and it is fairly safe to argue that it could not take place in large masses of grain in air-tight storage. This treatment also prevents the growth of moulds and preserves the wheat from becoming rotten even in the presence of a high excess of moisture,

FIG. 2.


TEMPERATURE (Centigrade)
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37
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DAYS
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45
50
55
60
65
70
75
A
A′
B
C

which was purposely exaggerated in our experiments in order to promote heating.*

It should be noted, however, that the damp wheat in the sealed flasks became distinctly acid, which might seriously impair its milling value. But it is not likely that anybody would attempt to store wheat with the abnormally high moisture content with which we experimented, and there are no grounds for believing that any serious acidity could develop in reasonably dry wheat under the same conditions. Indeed, the Maltese experience communicated to us by Prof. Zammitt goes to show that no evil effects result from air-tight storage [Dendy, 1918]. It is, on the other hand, quite possible that this method would permit of the storage of grain of a higher moisture content than usual, owing to the prevention of heating; but, from other points of view, the limit of safety as regards moisture for wheat intended for prolonged storage in air-tight silos remains to be determined by experiments on a large scale.

Returning to the consideration of the temperature curves of the heating wheat in our two experiments we may emphasize one peculiarity which both exhibit and to which we have already referred. That is the appearance of two maxima, separated by a considerable interval of time. In other words, after the first period of heating there is a fall of temperature, followed by another rise to a higher point than before. It has been suggested to us that this may indicate that two distinct processes of fermentation are involved and we would suggest that while the first is due to enzymes in the grain itself the second may be due to microbic fermentation resulting in the rotting of the wheat. There is obviously room here for further investigations of an interesting character.†

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* In another experiment at room temperature, with wheat having a moisture content of only 19·3 per cent., heating progressed much more slowly, the rise of temperature being only about 3° C. for the first eight weeks. Then, with the advent of warmer weather in June, it began to increase fairly rapidly, rising about 10° C. in nine days. In a sealed companion flask no heating took place.

† Compare Newstead and Duvall [1918].

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TABLE OF CONTENTS.

Page.

1. Introduction 3

2. The Gases present in Air-tight Vessels in which Weevils have been killed 7

3. The Carbon Dioxide given off by Wheat in Air-tight Vessels 11

4. The Carbon Dioxide given off by Weevils in Air-tight Vessels 19

5. The Respiratory Quotient of Weevils 21

6. The Effect of Diminished Oxygen Pressure upon Weevils... 26

7. The Poisonous Effects of Carbon Dioxide 31

8. Summary of Results given in Part III 42

9. General Discussion on the Efficacy and Advantages of Air-tight Storage for Cereals 43

List of Literature referred to 50

REPORT ON THE EFFECT OF AIR-TIGHT STORAGE UPON GRAIN INSECTS.—PART III.

By ARTHUR DENDY, D.Sc., F.R.S., Professor of Zoology in the University of London, and

H. DOUGLAS ELKINGTON, B.Sc., F.I.C.

1. INTRODUCTION.

In this, the concluding part of our Report, we propose, before summarising the whole of our results and briefly stating the complete case for air-tight storage, to deal with the chemical and physiological problems connected with the destruction of insect life in hermetically sealed vessels. We have already demonstrated (1918), by numerous experiments, that grain insects, like most other animals, cannot continue to live in an atmosphere that is never renewed by ventilation, in spite of a widely spread belief to the contrary. It remained to determine, as accurately as possible, what are the factors concerned in the death of the insects under such circumstances, and what is the composition of the atmosphere in air-tight vessels in which insects have been killed, whether in the presence or absence of grain.

It has long been a matter of general knowledge that carbon dioxide accumulates in large quantities in closed receptacles containing grain, and it seemed highly probable that the destruction of insect life in such cases was due either to the poisonous action of the carbon dioxide or to the deprivation of oxygen, or to a combination of both these factors. It was by no means impossible, however, that other factors, such as the presence of other poisonous gases, might contribute to the result. The problem could only be solved by careful chemical and physiological investigation, occupying a very large amount of time and involving much labour. It was thought worth while to undertake this, with a view to obtaining precise and detailed information on a subject of great economic importance, and it is hoped that the results will prove of considerable interest from the purely physiological, as well as from the economic, point of view.

The very numerous chemical analyses, upon which the conclusions arrived at depend, were carried out entirely by Mr. H. Douglas Elkington, aided by a grant of money from the Royal Society, and the following observations on the methods of analysis generally employed may be most conveniently inserted here, leaving the account of special methods, required for special purposes, to be given in the appropriate sections.

We are glad to take the opportunity in this place of expressing our indebtedness to our colleague, Dr. O. Rosenheim, who has assisted us greatly both by the loan of apparatus and by valuable suggestions as to physiological methods of investigation.

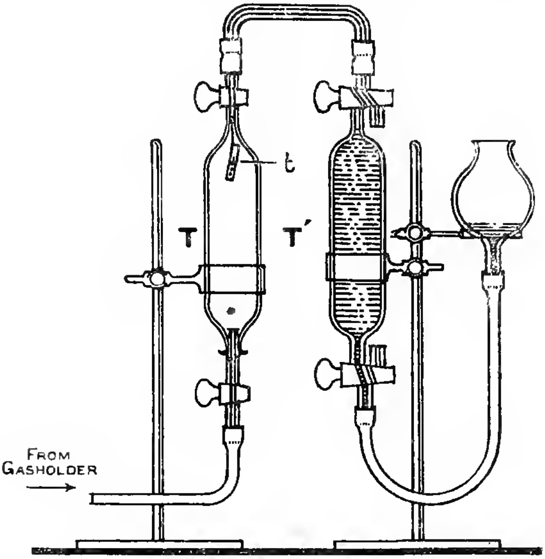
Carbon dioxide was determined either by direct weighing, or else volumetrically. When the first method was used, the gases contained in a given flask were driven out with a current of dry air, free from CO_2, into an absorption apparatus. This consisted of five pairs of tubes. The first two pairs, for drying the gases, contained pumice soaked in strong sulphuric acid; the third and fourth pairs contained moist soda-lime, in the first tube, for absorption of CO_2, and pumice soaked in sulphuric acid, for the absorption of moisture given off by the soda-lime, in the second; the fifth pair, acting as guard tubes, contained pumice soaked in strong sulphuric acid in both. All these tubes were prepared according to the method given by Haldane and Pembrey (1890). Pure dry air was always passed through the whole apparatus before the tubes were weighed at the commencement of an experiment. Similar pairs of tubes were used as counterpoises.

The absorption, both of the water and of the carbon dioxide, was very efficiently effected in the first of each appropriate pair of tubes, and the use of soda-lime enabled a fairly rapid current of dry air to be passed through the flask. When sufficient air had passed through to drive out all the CO_2, the absorption tubes were again weighed against their respective counterpoises, after being allowed to stand at least half an hour to regain the original temperature.

When the percentage composition by volume of the gases contained in the sealed flasks was required, these were extracted over mercury into a gas-sampling tube, and from this samples were withdrawn for analysis in Haldane's gas apparatus. The apparatus used was made by Rittershaus, London, and the burette was correctly calibrated, as shown by testing it according to the methods given by Haldane (1912). In nearly all cases the results given in the tables represent the mean of two close analyses.

In experiments dealing with the effects of pure gases and mixtures of gases upon weevils the following general method was used. The weevils, usually 10 in number, together with five grains of killed wheat for feeding purposes, were placed in a small glass tube (4 by 1 cm.) covered at each end with cambric tied on with cotton. This small glass tube (*t*) was suspended internally from the neck of a specially constructed gas tube (of between 57 and 60 c.c. capacity) by means of cotton attached to a cork ring (see Fig.). In this way the small inner tube did not come into contact with the mercury when the gases were withdrawn for analysis.

The specially constructed gas tube (T) was provided with a glass stopper tap at the bottom, which could be removed in order to insert the small tube (*t*) and which was tied on during the period of sealing for the sake of extra security. A special mixture of paraffin-wax, vaseline and india-rubber was used for the glass taps in the gas tubes, and in other pieces of apparatus, for rendering these air-tight.



The gas mixtures were made up over water in a large inverted glass cylinder. From this they were driven through the gas tube (T) and then out through a capillary tube attached to the two-way cock of a gas-sampling tube (T′). When enough of the mixture had been passed through the tube to displace all the air in T, the two-way cock was turned and a sample was withdrawn into the gas-sampling tube T′ (previously filled with mercury) and analysed as soon as possible. About the same time the stopcocks of the gas tube T were turned and this, with the weevils in the inner tube, was then removed and incubated. At the end of an experiment, when all the weevils were apparently dead, the gas tube was opened under mercury and a sample withdrawn for analysis in the usual way.

For the purpose of making artificial mixtures of gases nitrogen was either prepared in the laboratory or obtained from the British Oxygen Co. In the former case it was prepared chemically from sodium nitrite, ammonium sulphate and potassium dichromate, and led through a combustion tube heated to dull redness and containing finely divided copper to decompose any oxides of nitrogen, and then into a gasholder. The purity of the nitrogen obtained in this way never exceeded 98 per cent. (2 per cent. of oxygen by analysis being present) and therefore the British Oxygen Company's product, containing 99·3 per cent. of nitrogen and 0·7 per cent. of oxygen, was used in most cases. The oxygen came from the same commercial source, while the carbon dioxide was prepared in a Kipp's apparatus and purified in the usual way.

The moisture content of the samples of wheat was determined by heating ten grammes in an electric oven kept at a temperature of 100—102° C. for 48 hours.

The wheats used for the sealing experiments described under Sections 2 and 3 were kept quite free from chances of weevil infection and representative samples were incubated for long periods to test for the presence of insects, with negative results in all cases.

In studying the effect of pure gases and mixtures of gases upon weevils the latter have sometimes to be sealed up for a good many days. It is well known that weevils require moisture for their existence, and this fact, together with the necessity for food, must be taken into account. In all cases in which the insects were subjected to the action of gases of known composition, these gases, or mixtures of gases, were accordingly saturated with moisture, and in many of our experiments (*e.g.*, all those described in Sections 6 and 7) a few grains of killed wheat (10–11 per cent. moisture content) were supplied to the weevils for feeding purposes. Direct experiment proved that weevils thrive and multiply freely when fed on this killed wheat.

In most cases ten weevils were used for each experiment. This small number was chosen in order that the weevils might be easily observed, and also that the death of the weevils might be safely attributed to the action of the gases used and not to the products formed by the putrefaction of any weevils which died before the conclusion of the experiments. Only active weevils were used for the experiments, and they were (except in exps. 110–113) picked out at random from cultures kept at the same temperature as that used for the experiment.

At the conclusion of each experiment, when all the weevils were apparently dead and the gases had been extracted over mercury, the small glass tube was removed from the gas tube, and incubated in a moist atmosphere at 30–31° C. for 48 hours to test for revivals. We may remind the reader that there is a period between the cessation of movement on the part of the weevils and their death. We made it a rule to allow 24 hours to elapse, after the weevils had become motionless, before opening the gas tube, in order to make reasonably sure that they were really dead, excepting in special cases as shown in the Tables.

The following two companion experiments were primarily intended to prove that the chemically prepared nitrogen used in some cases had no injurious effect upon the weevils, but they also serve to illustrate the necessity for this extra period of incubation. Two gas tubes, of between 57 and 60 c.c. capacity, each containing ten *Calandra oryzae* and five grains of killed wheat in a small inner tube, were filled, one with pure moist air (21·05 per cent. oxygen), and the other with an artificial mixture containing 0·83 per cent. CO_2, 22·88 per cent. oxygen and 76·29 per cent. (by difference) of chemically prepared nitrogen, sealed, and incubated at 30–31° C. In the first tube the weevils were all moving after 220½ hours, but motionless after 237 hours. The tube was opened after 243 hours and analysis gave 19·94 per cent. CO_2, 0·18 per cent. O_2, and 79·88 per cent. N. (by diff.). The small tube containing the apparently dead weevils was incubated at 30–31° C., and in 1½ hours several weevils showed movement. In 24 hours, eight weevils had recovered, but were still feeble, and in 48 hours these eight were alive, active, and some were feeding. In the second tube three weevils had become motionless in 192 hours, and the rest were feeble at the end of this time. The remaining seven weevils showed movement till between 212 and 236 hours and the analysis was made after 240½ hours. This gave 22·49 per cent. CO_2, 0·13 per cent. O_2, and 77·38 per cent. N (by diff.). On incubation the seven weevils recovered in 24 hours, and were still alive at the end of 48 hours.

2. THE GASES PRESENT IN AIR-TIGHT VESSELS IN WHICH WEEVILS HAVE BEEN KILLED.

So long as the grain remains fairly clean and not seriously contaminated by faecal matter, the only gases present in flasks in which wheat and weevils have been sealed up appear to be carbon dioxide, oxygen and nitrogen. Specific tests have been made for hydrogen, marsh gas, carbon monoxide and ammonia, but without result. It is obvious, therefore that, since nitrogen has no physiological action, the lethal effect must depend upon the proportion of carbon dioxide and of oxygen respectively present in the mixture. This proportion was determined volumetrically in the usual way.

Table I shows the results of six experiments, with corresponding controls, made in each case with 40 grammes of wheat and (except in the controls) 50 specimens of *Calandra oryzae*. The weevils were all taken from cultures at 30–31° C., and this temperature was maintained throughout the experiment.

Hermetically sealed gas tubes, of the kind described in the Introduction, were used as containers. These were practically filled with the wheat and weevils and a rapid current of pure dry air was passed through the tubes for a minute or two before they were sealed (at room temperature), in order to remove the carbon dioxide initially present in the atmosphere. The moisture present in the wheat would be ample for the requirements of the insects.

TABLE I.—Effect of Incubating 50 *Calandra oryzae* and 40 Grammes of Wheat in Sealed Tubes at 30–31° C.

No. of Experiment.	Variety of Wheat.	Moisture Content of Wheat at Commencement of Experiment.	Time till Weevils became Motionless (in Hours).	Period of Incubation (in Hours).	Percentage Composition of Gases at the Time of Opening.		
					CO_2.	O_2.	N (by diff.).
1	English	13·8	24–67	67	13·77	0·32	85·91
Control	,, ...	,,	—	,,	1·51	18·69	79·80
2	English	13·8	0–24	48	9·12	0·48	90·40
Control	,, ...	,,	—	,,	0·61	19·53	79·86
3*a*	English	13·8	0–24	48	12·74	0·25	87·01
3*b*	,, ...	,,	0–24	,,	13·11	0·32	86·57
Control	,, ...	,,	—	,,	0·78	19·50	79·72
4*a*	No. 1 North Manitoba	12·15	0–48	48	12·22	0·22	87·56
4*b*	,,	,,	0–48		11·87	0·31	87·82
Control	,,	,,	,,	,,	0·25	20·28	79·47

None of the insects revived on being tested in the usual way.

It will be seen from this Table that nearly all the oxygen initially present in the air was used up before the weevils succumbed, the final percentage of carbon dioxide ranging from 9·12 to 13·77, and of oxygen from 0·22 to 0·48. The percentage of nitrogen at the close of the experiment was determined only by difference and the result is at first sight anomalous. This anomaly, however, is partly explained when we remember that the respiratory quotient of the weevils is less than 1, the amount of oxygen consumed being greater than the amount of carbon dioxide given out, so that the total volume of gas present is diminished. We shall discuss this matter further in connection with Table II.

The control experiments, without weevils, show that, under the conditions given, the wheat played a very small part in the consumption of oxygen and the production of carbon dioxide, but it played a very important part in the reduction of the available air space, which is diminished to about 38 per cent. in vessels completely filled with wheat.

Table II shows the results of a series of experiments in which insects were killed in hermetically sealed gas tubes each containing only 50 grains of killed wheat as a food supply, so that the lethal effect might be attributed entirely to the metabolic activity of the insects themselves. In each case 100 insects (*Calandra oryzae*, *C. granaria* or

Rhizopertha dominica) were sealed in a tube having a capacity of 57–60 c.c. At the commencement of each experiment pure moist air, containing 21·05 per cent. of oxygen, was passed through the tube before sealing. The tubes were then incubated at 30–31° C. When a sufficient period had elapsed to make sure that none of the weevils would revive, the tubes were opened for analysis in the usual way. All the dead insects were tested as usual and none revived. Control tubes containing 50 grains of killed wheat without any insects showed that the amount of carbon dioxide produced was negligible (0·13–0·14 per cent.) as also was the consumption of oxygen.

Table II.—Effect of Incubating 100 Insects in Sealed Tubes at 30–31° C.

No. of Experiment.	Species.	Time till Insects became Motionless (in Hours).	Period of Incubation (in Hours).	Percentage Composition of the Gases at the Time of Opening.		
				CO_2.	O_2.	N (by diff.).
5	*C. oryzae*	54–72	72	17·72	0·18	82·10
6	*C. oryzae* ..	54–72	72	17·97	0·12	81·91
7	*C. granaria*	48–96	96	16·10	0·23	83·67
8	*C. granaria*	27–45	72	16·72	0·07	83·21
9	*R. dominica*	48–96	96	16·72	0·04	83·24
10	*R. dominica*	44–68	92	16·62	0·07	83·31

In comparing Tables I and II it will be seen that—as regards *C. oryzae*—the production of carbon dioxide appears to be considerably less in the former than in the latter series of experiments, though in both cases practically all the oxygen has been consumed. The apparent deficiency of carbon dioxide shown in Table II can probably be accounted for entirely by the fact that the respiratory quotient of the weevils is less than 1 (see Section 5), but this is not sufficient to account entirely for the greater deficiency shown in Table I. In endeavouring to account for this we must consider the different conditions of the two series of experiments. In the case of Table I the receptacles containing the weevils were nearly filled with live wheat, in that of Table II they contained only 50 grains of killed wheat and consequently a very much larger air space. The deficiency of carbon dioxide in the vessels containing live wheat obviously cannot be accounted for by the metabolic activity of the wheat itself, but we would suggest that there may have been a mechanical absorption of CO_2 over the surface of the wheat; on the other hand, it is conceivable that the difference in the total air space may have exercised some effect upon the metabolism of the weevils.

In order to show that the apparent difference in CO_2 production in these cases is not illusory we carried out the special experiments Numbered 11 and 12 and shown in Table III, which entirely confirm the results previously obtained.

In Experiment 11, 40 grammes of live wheat (No. 1 North Manitoba), having a moisture content of 12·15 per cent.; were sealed up with 100 *Calandra oryzae*, the total air space remaining being 28 c.c. A control was run at the same time without the weevils. In Experiment 12, 100 *Calandra oryzae* were sealed up with 50 grains of killed wheat, the air space remaining being 58 c.c. The weevils were incubated as usual at the close of the experiments, without showing any revivals.

Table III.—Effect of incubating 100 *C. oryzae* at 30–31° C. in Sealed Tubes under different Conditions as regards the Presence of Wheat and the Air-space.

No. of Experiment.	Approximate Air Space and Wheat Present.	Time till Weevils became Motionless (in Hours).	Period of Incubation (in Hours).	Percentage Composition of the Gases at the Time of Opening.		
				CO_2.	O_2.	N (by diff.).
11	28 c.c. air and 40 grammes live wheat	0–21½	49¼	12·85	0·15	87·00
Control without weevils	40 grammes live wheat	—	49¾	0·19	20·42	79·39
12	58 c.c. air and 50 grains killed wheat	20–43½	72	17·19	0·0	82·81

It will be seen that in Experiment No. 12, with the relatively large air space, the percentage of carbon dioxide present at the close was much higher than in Experiment No. 11, with a much smaller air space. It is true that the period of incubation was longer, because it took longer for the weevils to succumb, but the difference in the percentage of CO_2 present was far greater than could be accounted for in this way, for in both cases practically all the oxygen was consumed, and the only possible way in which CO_2 could have been produced after the death of the weevils would have been by some unknown anaërobic process of decomposition.

The general conclusions to be derived from the experiments described in this section are that grain insects (Calandra and Rhizopertha) in hermetically sealed vessels succumb as soon as the supply of oxygen is exhausted, and that before doing so they produce an amount of CO_2 equivalent to the amount of oxygen consumed (allowance being made for the fact that the respiratory quotient is less than 1). Nitrogen, oxygen and carbon dioxide are the only gases found in the sealed vessels.

3. THE CARBON DIOXIDE GIVEN OFF BY WHEAT IN AIR-TIGHT VESSELS.

The amount of carbon dioxide produced by the wheat was determined either by weight, as described in the Introduction, or volumetrically (as a percentage of the gases present in the receptacle at the close of the experiment), Haldane's apparatus being employed in the latter case. Those experiments in which the carbon dioxide was determined by weight were all made in glass flasks of a capacity varying with the quantity of wheat taken. In the different experiments of a series, such as those given in Tables IV and V, and in duplicate experiments, the flasks had approximately the same volume. In all cases, whether the carbon dioxide was to be determined by weight or by volume, the wheat very nearly filled the flasks, the object being to follow the conditions of a silo filled with grain. In the experiments given in Table IV flasks having ground-glass stoppers and delivery tubes fitted with glass taps were used, but those shown in Table V were made in flasks provided with two-holed rubber corks fitted with glass delivery tubes drawn out ready for sealing. The rubber corks were thoroughly waxed inside and out, to prevent escape or absorption of CO_2, and the joints between the corks and the necks of the flasks were similarly treated.

When an experiment was commenced the glass delivery tubes (when not provided with taps) were sealed in the blowpipe, the atmospheric temperature and pressure being noted. The flasks were then either placed in incubators or in a dark cupboard in the laboratory. At the time of analysis thick-walled rubber tubing was placed over the ends of the delivery tubes and attached on the one side to a drying and purifying apparatus and on the other to the absorption apparatus.

The ends of the sealed glass tubes were broken and a current of dry air free from CO_2 was passed through the flask to expel water and carbon dioxide. When the wheat contained a high percentage of moisture this process took a long time.

The approximate air-space in the flasks was found by using xylene, but probably this penetrated the grains to some extent and gave a fictitiously large air-space. The percentage of carbon dioxide was calculated in the usual way.

In the experiments given in Table IVA, where the percentage of carbon dioxide and oxygen by volume was determined directly, glass cylinders having tightly fitting glass stoppers were used. These glass stoppers were tied to the cylinders and paraffin wax was added as before to ensure the hermetical sealing. The actual air space in these cylinders, filled with 50 grammes of wheat, was approximately half that of the above flasks filled with 100 grammes of wheat.

In Table VA flasks of the same capacity as those in Table V were used. The flasks were provided with rubber corks, waxed as before, having a short glass tube which was drawn out, and sealed when an experiment was started.

It will be observed by comparison of Table IV with IVA and V with VA that, with one exception, the percentage of carbon dioxide determined by calculation from the weight of CO_2 and the air-space is greater than that determined by direct volumetric analysis. We account for this, tentatively, by supposing that in the former case a certain amount of carbon dioxide is driven out of the grains themselves by the current of dry air passed through the wheat, but it must also be remembered that the correspondence as regards the proportion of air-volume to wheat volume throughout the two series is only approximate.

TABLE IV.—Amount of Carbon Dioxide given off in Seven Days by 100 Grammes of Mixed English Wheat of Different Degrees of Moisture Content.

No. of Experiment.	Initial Moisture Content.	Temperature during Experiment.	Weight of CO_2 given off (in Milligrammes).	Calculated Approximate Percentage of CO_2 in Flask at close of Experiment.
13	18·70	30–30·4° C.	52·6	35·70
14		20–22° C.	25·3	18·22
15	17·25	30–30·4° C.	25·9	21·30
16		20–22° C.	17·9	14·45
17	16·95	30–30·4° C.	28·9	19·37
18		20–22° C.	20·1	14·43

TABLE IV—*continued.*

No. of Experiment.	Initial Moisture Content.	Temperature during Experiment.	Weight of CO_2 given off (in Milligrammes).	Calculated Approximate Percentage of CO_2 in Flask at close of Experiment.
19	15·10	30–30·4° C.	21·3	14·11
20		20–22° C.	3·3	2·31
21	13·25	30–30·4° C.	3·3	2·20
22		20–22° C.	1·4	0·98
23	12·0	30–30·4° C.	0·6	0·48
24		20–22° C.	0·2	0·16

In the experiments given in the above Table the samples of wheat employed are arranged in six grades, according to moisture content. The natural moisture content of the original sample (mixed English) was 18·7 per cent. The lower grades were obtained by drying sub-samples at a gentle heat. The moisture content of the sub-samples was directly determined after drying. The two experiments of each pair were conducted simultaneously, but at different temperatures, and all the experiments were carried out between April 16th and May 30th. 1919.

TABLE IVA.—Percentage of Carbon Dioxide and Oxygen in Cylinders in which 50 Grammes of Wheat had been Sealed up for Seven Days under the same Conditions as in Table IV.

No. of Experiment.	Initial Moisture Content.	Temperature during Experiment.	Percentage Composition of the Gases present at the Time of Opening.		
			CO_2.	O_2.	N (by diff.).
25	18·7	30–30·4° C.	29·62	0·0	70·38
26		20–22° C.	15·05	0·1	84·85
27	17·25	30–30·4° C.	19·09	0·14	80·77
28		20–22° C.	—	—	—

TABLE IVA—*continued.*

No. of Experiment.	Initial Moisture Content.	Temperature during Experiment.	Percentage Composition of the Gases present at the Time of Opening.		
			CO_2.	O_2.	N (by diff.).
29	16·95	30–30·4° C.	—	—	—
30		20–22° C.	13·07	1·49	85·44
31	15·1	30–30·4° C.	10·58	5·59	83·83
32		20–22° C.	2·14	17·39	80·47
33	13·25	30–30·4° C.	1·98	17·45	80·57
34		20–22° C.	—	—	—
35	12·0	30–30·4° C.	0·41	20·10	79·49
36		20–22° C.	0·25	20·48	79·27

In the above Table are shown the results obtained by direct volumetric analysis, as regards CO_2 and O_2, in a series of companion experiments conducted simultaneously with those given in Table IV. The same wheat was employed, but in half the quantity, 50 grammes only being available.

TABLE V.—Amount of Carbon Dioxide given off at Room Temperature (average 20° C.) in 14 days by 100 Grammes of Canadian Wheat of different Degrees of Moisture Content.

No. of Experiment.	Initial Moisture Content.	Weight of CO_2 given off (in Milligrammes).	Calculated Approximate Percentage of CO_2 in Flask at close of Experiment.
37	12·7	0·8	0·84
38	13·35	1·2	1·02
39	14·75	5·9	4·72
40	16·0	21·8	16·75
41	16·9	27·3	21·51
42	18·7	41·0	33·57

In the above Table the samples of wheat employed are again arranged in six grades according to moisture content. The natural moisture content of the original sample (No. 1 North Manitoba) was 12·7 per cent., and the higher grades were obtained by damping sub-samples. The calculated amount of water necessary to bring the wheat to the desired moisture content was added, and the damped wheat allowed to stand in a stoppered bottle for four days to ensure equal distribution of moisture. The actual moisture content was determined as usual by direct analysis. Each experiment was started either on May 27th or 28th.

TABLE VA.—Percentage of Carbon Dioxide and Oxygen in Flasks in which 100 Grammes of Wheat had been Sealed up for 14 days under the same Conditions as in Table V.

No. of Experiment.	Initial Moisture Content.	Percentage Composition of the Gases present at the Time of Opening.		
		CO_2.	O_2.	N (by diff.).
43	12·7	0·45	19·36	81·19
44	13·35	0·81	18·90	80·29
45	14·75	3·10	14·89	82·01
46	16·0	13·95	0·31	85·74
47	16·9	17·00	0·08	82·92
48	18·7	21·11	0·0	78·89

As in the case of Table IVA the results here shown were obtained by direct volumetric analysis. The wheat employed was, of course, the same as in Table V, and the experiments in the two Tables were carried out concurrently.

In considering the results given in these Tables it should be remembered that Bailey and Gurjar (1918) have shown that freshly damped wheat does not give off so much carbon dioxide as natural wheat of the same moisture content, but the difference appears to be very slight for moisture contents below 13 per cent.

An inspection of Tables IV and V brings to light some very interesting facts with regard to the amount of carbon dioxide given off by wheat in sealed vessels under various conditions, and the same facts are clearly demonstrable from Tables IVA and VA, which show a striking agreement with the companion series.

(1) The amount of carbon dioxide given off is proportional to the moisture content of the wheat. In Tables IV and IVA a progressive decrease in moisture content is seen to be accompanied by a corresponding decrease in the amount of CO_2, while in Tables V and VA a progressive increase in moisture content is seen to be accompanied by a corresponding increase in the amount of CO_2 produced.

(2) Tables IV and IVA also show that the amount of CO_2 given off varies with the temperature. It is well known that the higher the temperature (within reasonable limits) the greater the amount of CO_2 produced.

(3) All four Tables bring out very clearly the fact that there is what may perhaps be called a " critical point " as regards moisture content, at which the rate of carbon dioxide production suddenly becomes very greatly increased (or diminished). With the hard Canadian wheat used in the experiments given in Tables V and VA, this point lies between 14·75 per cent. and 16 per cent. of moisture, at a temperature of about 20° C. With soft English wheat (Tables IV and IVA) it lies between 15·1 per cent. and 16·95 per cent. at a temperature of 20–22° C.

(4) The position of the critical point appears to vary with the temperature, for whereas at 20–22° C., it lies between 15·1 per cent. and 16·95 per cent. for soft English wheat, at 30–30·4° C. it lies between 13·25 per cent. and 15·1 per cent.

Tables IVA and VA show the vitiation of the atmosphere in the sealed receptacles as determined by direct volumetric analysis. It will be seen that when English wheat having a natural moisture content of 18·7 per cent. is sealed up in a receptacle of approximately its own volume, at a temperature of 20–22° C., practically the whole of the oxygen is used up in seven days. Table VA shows a similar result for Manitoba wheat damped to 18·7 per cent. of moisture and sealed for 14 days. In these cases it would take a very short time for the wheat to render itself absolutely immune from insect attack when stored in an air-tight receptacle. With very dry wheat, on the other hand, the rate of carbon dioxide production and oxygen consumption is so low that it would take a comparatively long time for the stored wheat to render itself immune. Thus Table VA shows that, with Manitoba wheat of about 12·7 per cent. moisture content, at the end of 14 days the atmosphere in the sealed receptacle still contained 19·36 per cent. of oxygen and only 0·45 per cent. of carbon dioxide. Table IVA shows a very similar result for English wheat dried to 12 per cent. of moisture. Nevertheless it would not take many months for even these dry wheats to render themselves immune.

We have made numerous experiments extending over much longer periods, both at room and incubator temperatures. Two of these only need be mentioned. Five hundred grammes of No. 1 North Manitoba wheat, having an initial moisture content of 10·2, were sealed for 157 days at laboratory temperature (September to February) in a flask which they very nearly filled. When opened, the air in this flask contained only 6·31 per cent. of carbon dioxide, as calculated from the actual weight (33·0 mg.) produced. A duplicate experiment, run concurrently, yielded 27·3 mg. of CO_2. In this case the dryness of the wheat and the lowness of the temperature were both very unfavourable to carbon dioxide production.

In the second case 100 grammes of English wheat, having a natural moisture content of 15·6 per cent., were sealed for 31 days at 30–31° C., yielding 19·6 mg. of CO_2, giving a calculated percentage of CO_2 in the atmosphere of 15·77. A duplicate experiment, run concurrently gave 19 mg. of CO_2.

It is evident from Tables IV, IVA, V and VA, that if wheat can be stored in air-tight receptacles with a moisture content above the "critical point," it will very soon render itself quite immune to insect attack, but that if the moisture content has to be below the critical point it will take a much longer time to bring about this result *by the action of the wheat alone.* Other factors in the problem, however, have also to be considered and we shall postpone the general discussion thereof till the close of this Report.

In the meantime we may point out that our conclusions as to the existence of a "critical point" as regards moisture content are in striking agreement with those of Messrs. Bailey and Gurjar (1918). These investigators approached the problem from an entirely different point of view, being concerned with the question of "Heating" due to fermentation (so-called Respiration), the degree of which they measured by the amount of carbon dioxide produced by the wheat. Their experiments were made at a temperature of 37·8° C., and their methods of analysis were quite different from ours, which renders the agreement in our results even more noteworthy. Speaking of a particular series of experiments, with samples of the same wheat graduated with regard to moisture content, they say, "The rate of increase in respiration is fairly gradual from 12·50 to 14·78 per cent., but after the latter percentage is exceeded, the rate is markedly accelerated. The break in the curve occurs when the moisture content slightly exceeds 14·5 per cent., and it is probable that this represents about the maximum percentage of moisture that this class of wheat may safely contain without danger of heating when stored in bulk." They also found that the amount of carbon dioxide produced varies according to the variety of wheat. Thus they say, "It may further be seen that the quantity of heat evolved by hard spring wheat containing 14·5 per cent. of moisture, as evidenced by the rate of respiration at that moisture content was evolved by these soft wheat samples when they contained about 13·6 to 13·8 per cent. of moisture. This is of interest, in view of the moisture limits prescribed in the United States Grain Standards for wheat, which are 14·5 per cent. for No. 2 hard spring, and 13 per cent. for No. 2 soft red winter, and the same for common white and white club wheat."

It seems probable, as indeed Bailey and Gurjar's remarks suggest, that the sudden increase in the rate of CO_2 production at the critical point of moisture content indicates the inauguration of some change in the processes of fermentation going on in the grain.

Tables IVA and VA bring out very clearly the fact that, within certain limits as regards moisture content, the volume of oxygen absorbed by the wheat is considerably in excess of the volume of carbon dioxide produced. We take this to mean that under the conditions given the respiratory quotient is less than one. The moisture limits within which this phenomenon is demonstrable will be seen to be 12 and 17·25 at 30–30·4° C., 12 and 18·7 at 20–22° C. (English wheat, Table IVA), and 12·7 and 16·9 (Manitoba wheat, Table VA). With higher moisture content the production of carbon dioxide is in excess of the consumption of oxygen and may apparently continue after all the oxygen in the air in the receptacle has been used up. Thus in Experiment 25, 29·62 per cent. of carbon dioxide was found on analysis after seven days sealing and a duplicate of the same experiment (not given in the Table) gave 42·69 per cent. after 14 days (at 30–30·4° C.). It results from these figures that a considerable increase of pressure must take place in the sealed vessels in which damp wheat is stored, and this may be easily demonstrated by means of a manometer attached to the receptacle.

The excessive production of carbon dioxide in sealed wheat of high moisture content must be attributed to anaërobic fermentation. Such fermentation is probably also responsible for the acidity observed in these cases. It is possible of course that other substances, such as alcohol and volatile acids, may be produced after all the oxygen has been consumed, and may have been incorrectly expressed as carbon dioxide.

Bailey and Gurjar (1918) have assumed that 1 gramme of respired carbon dioxide is equivalent to 2·6 calories of heat, but it seems obvious that this relation can apply only to aërobic "respiration." Our own experiments on heating (1919) show that no measurable rise of temperature takes place when damp wheat is kept in air-tight receptacles, although, as already seen, the percentage of carbon dioxide in the air in such vessels may rise at least as high as 42·69, obviously as the result of anaërobic fermentation.

Another factor that requires consideration and which is intimately connected with the foregoing is the depressing action of accumulating carbon dioxide upon the rate of so-called respiration. Kidd (1916) came to the conclusion that the rate of *anaërobic* CO_2 production in plant tissues is depressed by carbon dioxide. Bailey and Gurjar (1918) have discussed the question with regard to wheat and their experiments indicate a similar depression in the rate of *aërobic* respiration. With wheat containing 15·05 per cent. of moisture, they find that when the CO_2 is allowed to accumulate in a sealed vessel the rate of production per day is 4·11 mg. per 100 grammes of dry matter for the first day, but only averages 1·11 mg. per day for the third four-day period (at a temperature of 37·8° C.). Many of our own analyses show similar results, although we have not conducted experiments especially from this point of view. To give one example :—A sample of mixed English wheat, having a moisture content of 14·35 per cent., sealed for 21 days at a temperature of 30–31° C., gave an average daily yield of 0·94 mg. of CO_2 per 100 grammes of dry matter. Another sample of the same wheat, sealed for 31 days at the same temperature, gave an average daily yield of only 0·73 mg. of CO_2 per 100 grammes of dry matter.

It might be necessary to take into account this depressing effect of the accumulation of carbon dioxide upon CO_2 production, in attempting to estimate the length of time required to render a silo immune from the attacks of insects. We do not attempt to discuss its significance from a biological point of view. The whole problem of carbon dioxide production by wheat is an extremely complex one, and it appears to us that the various factors concerned still remain to be unravelled. We content ourselves with the empirical demonstration of certain facts which have an important bearing upon the problem of air-tight storage.

4. THE CARBON DIOXIDE GIVEN OFF BY WEEVILS IN AIR-TIGHT VESSELS.

The experiments in this series were all made in the glass flasks having ground-glass stoppers and glass taps described under Section 3. In all cases the weevils used for the experiments were taken from freshly made cultures kept at the particular temperature of the experiment. By adopting this precaution we found that the weevils were obtained in a cleaner condition and the introduction of moulds and bacteria was minimised. Fifty grains of killed wheat were used for feeding purposes in each experiment. Controls with 50 grains of killed wheat without weevils showed that the CO_2 produced was not a weighable quantity.

The flasks were sealed at room temperature and either placed in the appropriate incubator or else kept in a dark cupboard at room temperature.

When the period of sealing was complete the flasks were opened and the CO_2 driven out by means of a rapid current of pure dry air. The carbon dioxide was determined by weight. It was of course impossible to be certain that all the CO_2 had been driven out of the flasks for the reason that the weevils continued to give off small quantities of this gas, but the error must be very small compared to the total amount of carbon dioxide evolved during the period of sealing.

It should be noted that the air space in the flasks (about 150 c.c.) was sufficiently large to ensure that the accumulation of carbon dioxide had no injurious effect upon the weevils. All the insects remained alive at the end of each experiment, and the percentage of CO_2 in the atmosphere of the flasks only rose to about 10. Of course even this amount may have had some effect upon the respiratory exchange, but, for the short periods of time involved, the results given in Table VII suggest that this may be regarded as negligible.

TABLE VI.—Amount of CO_2 given off by 100 *Calandra oryzae* in 24 hours at 30·2° C.

No. of Experiment.	Weight of Weevils in Grammes.	Weight of CO_2 given off in Milligrammes.
49	0·169	28·7
50	0·1657	30·0
51	0·164	29·8

The results of the experiments given in the above Table are very consistent, and if we take the mean we arrive at the fairly safe conclusion that, at about 30° C., 100 *Calandra oryzae* give off about 29·5 mg. of carbon dioxide in 24 hours, that is to say, nearly a fifth of their own weight!

TABLE VII.—Amount of CO_2 given off by 100 *Calandra oryzae* at 20–21° C.

No. of Experiment.	Weight of Weevils in Grammes.	Period of Incubation (in Hours).	Weight of CO_2 given off in Milligrammes.
52	0·1704	48	17·9
53	0·1746	48	20·6
54	0·1721	24	9·4
55	0·1755	24	8·9

If we take the mean result of the four experiments given in this Table we arrive at the conclusion that, at 20–21° C., 100 *Calandra oryzae* give off only about 9·38 mgs. of carbon dioxide in 24 hours. This Table also shows that the amount given off in 48 hours is approximately twice that given off in 24 hours, there being no evidence of depression owing to the accumulation of CO_2.

TABLE VIII.—Amount of CO_2 given off by *Calandra oryzae* and *C. granaria* respectively at Room Temperature (about 18–19° C.).

No. of Experiment.	Number and Species of Weevils.	Weight of Weevils in Grammes.	Period of Incubation (in Hours).	Average Temperature during Experiment.	Weight of CO_2 given off in Milligrammes.
56	100 *Calandra oryzae.*	0·201	48	18° C.	23·6
57	100 *Calandra granaria.*	0·2356	48	18° C.	19·8
58	300 *Calandra oryzae.*	0·4637	6	19° C.	11·5
59	300 *Calandra granaria.*	0·6148	6	19° C.	11·9

Owing to the fluctuation of the room temperature it is impossible to make a reliable comparison of the results shown in this Table with those previously given, but at any rate there is no serious discrepancy. The experiments were intended to show whether or not the two species of weevil differed as regards CO_2 production. Nos. 56 and 57 (run concurrently) indicate that *C. granaria* gives off appreciably less CO_2 than *C. oryzae*, even if we take into consideration only the number of weevils, while the difference appears much greater when we take into account the fact that 100 *C. granaria* weigh considerably more than 100 *C. oryzae*. Experiments 58 and 59 (run concurrently) show the same result in relation only to the weights of the weevils, the actual amount of CO_2 produced being very slightly higher in the case of *C. granaria*. It seems safe to say, however, that weight for weight, *C. granaria*, at about 18–19° C., gives off less CO_2 than *C. oryzae*, a result which is quite consistent with its less active habits.

5. THE DETERMINATION OF THE RESPIRATORY QUOTIENT FOR CALANDRA ORYZAE AND CALANDRA GRANARIA.

For measuring the respiratory exchange of gases for these weevils the differential blood gas apparatus described by Barcroft* and Roberts

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* We desire to express our indebtedness to Mr. Barcroft for valuable advice in connection with the use of this apparatus.

(1910) was adapted for use. With the slight modifications in manipulation and technique described below the apparatus gave very satisfactory results.

In carrying out the experiments the methods given by Krogh (1914) (*a*) were closely followed. Two similar pieces of apparatus were used. In each of the containers of apparatus 1 a drop of water was placed, while in each of the containers of apparatus 2, two c.c. of 4 per cent. NaOH were placed. Since weevils vary in size and activity an average result was obtained by selecting at random lots of 50 weevils from fresh cultures kept at about 30° C. The weevils were weighed in a small glass-stoppered weighing bottle and afterwards cooled to about 5° C. for a few minutes to reduce their activity. While still sluggish, they were quickly enclosed in pairs of small silk gauze bags, tied with very thin platinum wire. The bags of each pair were lettered *a* and *b* and *a* was suspended from the neck of the left hand container of apparatus 1, while *b* was similarly placed in that of apparatus 2 (containing the soda solution). Both pieces of apparatus were then transferred to a thermostat filled with water (which was kept exactly at 30° C. by constant mechanical stirring) and allowed to remain there, open to the air, for 20 minutes, so that uniformity of temperature might be established. At the end of the 20 minutes both pieces of apparatus were closed within a short time of one another.

Clove oil was used as a manometer liquid, 10,000 mm. of this corresponding to 760 mm. of mercury. The level of the clove oil in the manometer limbs was adjusted by means of the central screws to the same starting point for each experiment, before the apparatus was closed. Two readings of the difference of pressure in the manometer limbs were taken for each experiment. After the second reading had been recorded the two silk bags were interchanged, so that the bag *a* was in apparatus 2 and the bag *b* in apparatus 1. The pieces of apparatus were then returned to the thermostat and 20 minutes allowed to elapse before they were again closed. Two further readings were made as before. The two different halves of two separate experiments were thus carried on simultaneously. Of course one experiment is concerned exclusively with the 50 weevils in bag *a* and the other with the 50 in bag *b*.

The volume of oxygen absorbed by the weevils, in cubic millimetres, was calculated from the following corrected formula given by Krogh (1914) (*b*).

$$d\left(\mathrm{A}p \cdot \frac{273}{273+tn} + \mathrm{v}.\frac{\mathrm{P}-f\mathrm{L}}{760} \cdot \frac{273}{273+t\mathrm{L}} \cdot \frac{\mathrm{A}+\mathrm{C}}{2\mathrm{C}}\right),$$

where d represents the observed difference of pressure in millimetres of the manometer limbs, A the volume of the container enclosing the weevils and the manometer limb above it, C the corresponding volume of the compensation container, P the atmospheric pressure, p the pressure of one millimetre of clove oil expressed in atmospheres, tn

and t_L the temperatures of the water bath and air respectively, v the volume of one millimetre of the manometer tube, whilst f_L is the water vapour tension corresponding to the air temperature.

A correction has to be made for the volume occupied by the silk bag *a* in the container of apparatus 1, and for the silk bag *b* and the 2 c.c. of 4 per cent. NaOH solution in the container of apparatus 2.

The volumes A and C were determined in the following way : After the last readings had been made the two silk bags *a* and *b* were removed from their containers and heated in an oven for five minutes at 55–60° C. to kill the weevils. The bags were then cooled and replaced in their respective containers. The total air space in the weevil container of apparatus 1 (or A corrected for the silk bag) was determined by the method and calculated from the formula given by Barcroft and Higgins (1911). The silk bag *a* in apparatus 1 was then transferred to apparatus 2 and a fresh determination made. The corrected volume for the bag *b* in each container and the volumes of each of the compensating containers were determined in the same way. By this simple modification a direct determination for the correction of the volumes occupied by the silk bags, which is very small compared with those of the containers, is rendered unnecessary. These corrected volumes were determined for every experiment. Of course we were unable to ascertain if any of the weevils contained in the bags had succumbed during the experiments, but it is highly improbable that they should have done so.

An actual experiment, in which the volume of the container in apparatus 1 was first determined without the silk bag and then with it, gave a correction for the volume occupied by the silk bag of 0·25 c.c. The volumes of all four containers in both pieces of apparatus only varied between 24 and 25 c.c., so that the correction $\frac{A+C}{2C}$ was very small indeed.

The value of v was determined by the method given by Barcroft and Higgins (1911). For apparatus 1 this was 1·754 cubic millimetres, which is very large compared with that obtained by Krogh (1914) with his micro-respiration apparatus, but he used a much narrower manometer tube.

The formula given above was also used for the calculation of the oxygen absorbed by the weevils + the carbon dioxide given off by the weevils and removed by the soda solution, correction of course being made for the 2 c.c. of NaOH solution itself.

Three pairs of experiments were made for each of the two species of weevil, and for each experiment two readings were made in most cases. The experiments were all made between July 21st and 29th, 1919, inclusive.

The results are given in the accompanying Tables, in which the brackets indicate simultaneous experiments (pairs).

TABLE IX.—Determination of the Respiratory Quotient for *Calandra oryzae*.

No. of Experiment.	Weight of 50 *C. oryzae* (in Grammes).	Duration of Experiment.	Cubic Millimetres of O_2 and CO_2 absorbed in Apparatus 2.	Cubic Millimetres of O_2 absorbed in Apparatus 1.	Cubic Millimetres of CO_2 given off.	Respiratory Quotient.	Calculated Milligrammes of CO_2 given off in 24 Hours per 100 Weevils.
60	0·0913	First Period (1 hour)	206·16	52·74	153·42	0·744	14·53
		Second Period (1 hour)	208·00	44·93	164·07	0·784	15·42
61	0·0879	First Period (1 hour)	252·99	64·12	188·87	0·746	17·88
		Second Period (1 hour)	243·55	61·74	181·81	0·746	17·21
62	0·0860	First Period (1 hour)	308·70	67·83	240·87	0·780	22·81
		Second Period (½ hour)	161·70	39·99	121·71	0·752	23·04
63	0·0889	First Period (1 hour)	366·60	53·59	313·01	0·853	29·64
		Second Period (½ hour)	161·30	33·10	128·20	0·794	24·28
64	0·0845	First Period (1 hour)	348·51	106·86	241·65	0·693	22·88
		Second Period (½ hour)	185·41	55·01	130·40	0·703	24·70
65	0·0901	First Period (1 hour)	365·20	67·37	297·83	0·815	28·20
		Second Period (½ hour)	191·73	38·69	153·04	0·798	28·98

In discussing the results shown in Table IX it must be remembered that the experiments were performed in pairs, those of each pair being conducted simultaneously. Each pair might thus be looked upon as constituting one experiment with 100 weevils, divided into two lots of 50 each, as already explained. If we take the mean result of all the readings, 12 in number, the respiratory quotient of *Calandra oryzae* works out at 0·767. Similarly the calculated amount of CO_2 given off by 100 weevils in 24 hours comes to 22·46 mg. It will be observed however, that the amount of CO_2 given off was very considerably smaller in the case of the first pair of experiments (Nos. 60 and 61) than in the case of the later ones (62–65), and this is also true for each of the first pair considered separately. The mean amount of the four determinations for the first pair is only 16·26, while that for the second pair is 24·94 and for the third pair 26·19. Similarly, the mean respiratory quotient given by the first pair of experiments is only 0·755, while that given by the two remaining pairs is 0·773. The discrepancy between the results given by the first pair of experiments and those given by the second and third pairs is so great that we are inclined to think there may have been some experimental error in the former. We have, therefore, decided to neglect the results of the first pair, and to take 0·773 as the respiratory quotient and 25·56 mgs. as the calculated amount of CO_2 given off by 100 *Calandra oryzae* in 24 hours at 30° C.

We have some evidence to show that the respiratory quotient of the larvae and pupae of *Calandra oryzae* is higher than that of the adults, being probably in the neighbourhood of 1 (*see* discussion of Table XVII in Section IX).

Table X.—Determination of the Respiratory Quotient for *Calandra granaria*.

No. of Experiment.	Weight of 50 *C. granaria* (in Grammes).	Duration of Experiment.	Cubic Millimetres of O_2 and CO_2 absorbed in Apparatus 2.	Cubic Millimetres of O_2 absorbed in Apparatus 1.	Cubic Millimetres of CO_2 given off.	Respiratory Quotient.	Calculated Milligrammes of CO_2 given off in 24 Hours per 100 Weevils.
66	0·1062	First Period (1 hour)	257·65	50·90	206·75	0·802	19·58
		Second Period (½ hour)	112·11	20·12	91·99	0·820	17·42
67	0·1021	First Period (1 hour)	306·29	53·65	252·64	0·821	23·92
		Second Period (½ hour)	138·62	22·65	115·97	0·836	21·96
68	0·1084	First Period (1½ hours)	382·75	63·44	319·31	0·834	20·16
		Second Period (1 hour)	293·24	55·55	237·69	0·810	22·51
69	0·1135	First Period (1½ hours)	583·41	80·09	503·32	0·862	31·77
		Second Period (1 hour)	333·18	73·80	259·38	0·778	25·66
70	0·1067	1 hour	271·26	55·51	215·75	0·795	20·43
71	0·1069	1 hour	222·96	45·10	177·86	0·797	16·84

Although this Table again shows considerable variation in the results of individual experiments, yet, if we compare the mean results of the three pairs of determinations, the difference is not very great, and the distribution of the figures is not such as to suggest an excessive experimental error for any particular pair. We have, therefore, taken the mean result of all the experiments in this case, which leads to the conclusion that, at 30° C., the respiratory quotient for *Calandra granaria* is about 0·815 and the amount of CO_2 given off in 24 hours by 100 weevils is about 22·02 mgs.

Krogh (1916) tells us that "The respiratory quotients met with in animals usually lie between 0·97 and 0·72." Our results as regards both species of weevil fall within these limits, a fact which is of considerable interest as indicating that the respiratory processes of these insects are thoroughly normal, and that they have no such powers of dispensing with a supply of free oxygen as has sometimes been supposed, a supposition which we have already shown by our experiments to be erroneous. Krogh further points out that the respiratory quotient of any particular animal serves as an indication of the nature of the substances catabolised. Thus the respiratory quotient for all carbohydrates is 1, that for fats is given as 0·707 and that for protein averages 0·80. A low respiratory quotient indicates that the material catabolised is chiefly fat and protein and a high one that it is chiefly carbohydrate and protein.

In the preceding section (Table VI) we arrived at the conclusion, from direct determination, that, at about 30° C., 100 *Calandra oryzae* give off about 29·5 mgs. of CO_2 in 24 hours. The calculated amount as shown in Table IX is only 25·56 mgs. This is not, however, a very serious discrepancy.* We also concluded, from direct experiment, that, weight for weight, *Calandra oryzae*, the more active of the two species, gives off more carbon dioxide than *C. granaria*, a conclusion which is fully borne out by the results shown in Tables IX and X.

6. THE EFFECT OF DIMINISHED OXYGEN PRESSURE UPON WEEVILS.

The part played by diminution of oxygen pressure in bringing about the death of grain insects in air-tight vessels is very clearly brought out in the following Table, showing the results of a series of experiments in which the amount of oxygen initially present ranged from 0·78 to 35·9 per cent., the rest of the atmosphere being nitrogen. The experiments were made in gas tubes as usual, each containing 10 specimens of *Calandra oryzae*, taken from cultures kept at 30–31° C. Five grains of killed wheat were supplied to the weevils in each tube and the tubes were incubated at 30–31° C. until the weevils had been all motionless for at least 24 hours. The dead weevils were in all cases tested for revival in the usual way, but without result.

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* Especially as the average temperature in the former case was really slightly higher (30·2 C.) than in the latter.

In order to show that the killed wheat supplied as food gives off only a negligible quantity of CO_2, a control experiment was carried out, in which five grains of killed wheat alone were sealed up in pure moist air, and incubated for 240 hours at 30–31° C., the conditions being exactly the same as for experiments 78 and 79, *minus* the weevils. At the close of the experiment the air in the tube contained only 0·15 per cent. of CO_2, while 20·88 per cent. of O_2 still remained.

In the last three experiments, in which the initial amount of oxygen was very large and the period of sealing consequently much prolonged, it was observed that the grains of killed wheat became mouldy and a certain amount of CO_2 was probably produced by the metabolism of moulds and bacteria.

TABLE XI.—Effect of Diminished Oxygen Pressure upon 10 *Calandra oryzae* in Sealed Tubes at 30–31° C.

No. of Experiment.	Percentage Composition of Gases at the Time of Sealing.		Time till all Weevils became Motionless (in Hours).	Period of Incubation (in Hours).	Percentage Composition of Gases at the Time of Opening.			Remarks.
	O_2.	N (by diff.)			CO_2.	O_2.	N (by diff.).	
72	0·78	99·22	2¾–19¾	44	0·47	0·27	99·26	After 2¾ hours, all weevils showed movement, but feeble. After 19¾ hours, all weevils were motionless. Grains of wheat untouched.
73	1·87	98·13	27–45¼	46	0·89	0·88	98·23	After 4 hours all weevils showed movement, but feeble. After 21 hours, four weevils showed movement, but only slight. After 27 hours, two weevils showed slight movement, and after 45¼ hours they were all motionless.
74	6·43	93·57	71–119	120¼	2·51	3·50	93·99	After 71 hours all weevils showed movement, but very feeble. After 119 hours, all were motionless.
75	6·56	93·44	77–125	125	1·73	4·20	94·07	After 19 hours, all weevils showed movement and some feeding. After 43 hours, only three weevils showed movement, and after 77 hours only one showed slight movement. After 125 hours all weevils were motionless.

76	10·78	89·22	192–216	239¼	5·97	3·94	90·09	After 24 hours all weevils showed movement. After 48 hours seven showed movement, but feeble. After 96 hours, two weevils showed slight movement, and one continued till 192 hours. After 216 hours all weevils were motionless.
77	13·91	86·09	187–235	283	13·11	0·10	86·79	After 67 hours all weevils showed movement and some feeding. After 115 hours seven showed movement, but feeble. After 187 hours, only one weevil showed movement, and after 235 hours, all were motionless.
78	21·05	78·95	168–216	240	19·34	0·39	80·27	After 72 hours all weevils showed movement and some feeding. After 144 hours 9 showed movement. After 168 hours 7 showed movement, and after 216 hours all were motionless.
79	21·05	78·95	168–216	240	17·52	1·95	80·53	After 72 hours all weevils showed movement, and after 144 hours, eight showed movement. After 216 hours, all were motionless.
80	23·06	76·94	240–288	312	18·74	2·51	78·75	After 72 hours, nine weevils showed movement and some were feeding. After 144 hours, seven showed movement. After 192 hours only three showed movement. After 240 hours, two showed slight movement, but all were motionless after 288 hours. The grains of wheat were slightly mouldy.

TABLE XI—*continued.*

No. of Experiment.	Percentage Composition of Gases at the Time of Sealing.		Time till all Weevils became Motionless (in Hours).	Period of Incubation (in Hours).	Percentage Composition of Gases at the Time of Opening.			Remarks.
	O_2.	N (by diff.)			CO_2.	O_2.	N (by diff.).	
81	29·76	70·24	186–210	234	28·20	0·34	71·46	After 162 hours all weevils showed movement and some feeding. After 186 hours four showed movement. After 210 hours all were motionless. The grains of wheat were mouldy.
82	35·90	64·10	494–518	542	28·21	1·92	69·87	After 24 hours all weevils showed movement. After 42 hours, seven showed movement. After 158 hours, four showed movement, but feeble After 470 hours, three weevils showed movement. After 490 hours, still showed feeble movement. After 518 hours, all were motionless. Wheat very slightly mouldy.

Although it is, from the nature of the case, impossible to give exact figures, it is evident from this Table that the survival period—or lethal period if one prefers that term—of weevils in hermetically sealed vessels is directly proportional to the amount of oxygen initially present.

With the purest nitrogen that could be obtained (Experiment 72), sealing for 44 hours was sufficient to kill all the weevils, and it is evident that lack of oxygen, and not the presence of carbon dioxide, was responsible for this effect.

With the lower initial percentages of oxygen (Experiments 73—76) the weevils were unable to use up all the oxygen before succumbing but with higher initial percentages very little oxygen remained unused at the close of the experiment. Thus, starting with pure moist normal air, containing 21·05 per cent. of oxygen (Experiments 78 and 79), only from 0·39 to 1·95 per cent. of oxygen remained at the close of the experiment. It will be seen from the Table that the oxygen consumption and carbon dioxide production suddenly jump up when the initial percentage of oxygen reaches between 10·78 and 13·91, and it is evident that a certain amount of oxygen must be present initially if the weevils are to be able to make the most of whatever quantity there may be. Probably there is some acclimatisation effect, the weevils being able to support the diminished oxygen pressure much better when they are gradually accustomed to it.

The increase in the percentage of nitrogen shown in all the experiments given in this Table in evidently due, as explained in previous sections, to the fact that the amount of oxygen consumed by the weevils is greater than the amount of carbon dioxide produced.

It is quite clear from the experiments described in the present Section that the complete absence of oxygen is alone sufficient to destroy weevils, although they are able to remain alive for a considerable time when only small percentages of oxygen are present.

7. THE POISONOUS EFFECT OF CARBON DIOXIDE.

A number of experiments have been made to test the poisonous effect of carbon dioxide, apart altogether from the question of diminished oxygen pressure.

In Table XII is shown the effect of increasing the initial percentage of carbon dioxide while maintaining the percentage of oxygen as nearly normal (20·96) as possible. This, of course, involves a corresponding variation in the percentage of nitrogen in the atmosphere but as this gas has no physiological action this may be disregarded.

The experiments were conducted in gas-tubes as described in the Introduction. Ten specimens of *Calandra oryzae* were placed in each small inner tube together with five grains of killed wheat for food. All the dead weevils were tested for revival at the close of each experiment in the usual way, but without result.

The nitrogen used in this series of experiments was chemically prepared.

TABLE XII.—Effect of Increasing Percentage of Carbon Dioxide while the Percentage of Oxygen remains approximately the same (30–31° C., ten *Calandra oryzae*).

No. of Experiment.	Percentage Composition of Gases at the Time of Sealing.			Time till all Weevils became Motionless.	Period of Incubation (in Hours).	Percentage Composition of Gases at the Time of Opening.			Remarks.
	CO_2.	O_2.	N (by diff.).			CO_2.	O_2.	N (by diff.).	
83	14·08	23·60	62·32	256–280 hours	283	22·56	13·88	63·56	After 18 hours, all weevils walking about and one pair copulating. After 64 hours, four weevils moving, but feeble. In 184 hours only two weevils moving, and in 256 hours, one weevil just moving.
84	23·22	20·36	56·42	18¾–43 hours	91	24·61	19·09	56·30	After 18¾ hours all weevils moving but very feeble.
85	50·06	20·43	29·51	18½–25¼ hours	43¼	51·79	18·81	29·40	After one hour all weevils alive but very feeble. After about 18½ hours, only very slight movement in two weevils.
86	78·58	21·41	0·01	0–3 mins.	21	79·38	20·61	0·01	

The above table shows: (1) that, at 30–31° C., weevils are killed in less than 12 days in an atmosphere containing from 14·08 to 22·56 per cent. of CO_2, although 13·88 per cent. of oxygen still remains. (2) The higher the initial percentage of CO_2 (up to a certain point) the more rapidly is the lethal effect produced, so that in an atmosphere containing from 78·58 per cent. to 79·38 per cent. of CO_2 all the weevils are killed in 21 hours, though 20·61 per cent. of oxygen still remains.

It we remember that in an initially normal atmosphere the weevils are able to use up practically the whole of the oxygen before succumbing, it will be evident that the result in these cases must be due to the poisonous effects of the carbon dioxide.

Tables XIII and XIV show the effect of very high initial percentages of carbon dioxide, with oxygen and nitrogen varying down to 0. The experiments in Table XIII were all performed upon ten *Calandra oryzae* at a temperature of 30–31° C., the period of sealing being 19 or 20 hours; those in Table XIV upon 100 individuals of each species of weevil at the varying temperature of the laboratory or of an exposed gallery, the period of sealing being six days. Chemically prepared nitrogen was used in experiments 87 and 89.

TABLE XIII.—Effect of Mixtures of Carbon Dioxide, Oxygen and Nitrogen compared with Effect of pure Carbon Dioxide, at 30–31° C. (ten *Calandra oryzae*).

No. of Experiment.	Percentage Composition of Gases at the Time of Sealing.			Time till all Weevils became Motionless.	Period of Incubation (in Hours).	Percentage Composition of Gases at the Time of Opening.			Number of Revivals alive at the End of 48 Hours' Incubation.	Observations on Weevils during Incubation to test for Revival.
	CO_2.	O_2.	N (by diff.).			CO_2.	O_2.	N (by diff.).		
87	78·58	21·15	0·27	0–3 mins.	19	79·70	20·04	0·26	0	No sign of movement in 48 hours though examined frequently.
88	79·47	4·26 air	16·27	?	20	79·94	3·89	16·17	0	No sign of movement in 48 hours.
89	77·89	0·77	21·34	0–3 mins.	20	77·93	0·61	21·46	1	In less than 1 hour, five weevils showed movement. After 48 hours one weevil was alive but very feeble, the rest showing no movement.
90	99·87	—	—	0–3 mins.	20	99·87	—	—	10	In 1 hour several weevils were moving their legs. After 3 hours they were all moving, some feeding and one pair copulating. After 48 hours they were all still alive and some were feeding.

TABLE XIV.—Effect of Mixtures of Carbon Dioxide, Oxygen and Nitrogen compared with Effect of pure Carbon Dioxide at low Temperatures (100 Weevils).

No. of Experiment.	Species of Weevil.	Percentage Composition of Gases at the Time of Sealing.			Time till all Weevils became Motionless.	Period of Incubation (in Days).	Temperature during Period of Incubation.			Percentage Composition of Gases at the Time of Opening.			No. of Revivals Alive at the End of 48 Hours' Incubation.	Observations on Weevils during Incubation to Test for Revival.
		CO_2.	O_2.	N (by diff.).			Av.	Max.	Min.	CO_2.	O_2.	N (by diff.).		
91	*Calandra oryzae*	99·78	—	—	0–3 mins.	6	4·5° C.	8·5° C.	1° C.	99·1	—	—	32	After about 1½ hours several weevils had recovered and were walking about. After 24 hours 63 weevils were alive and walking. After 48 hours 32 weevils were alive and some were feeding. After 77 hours only 20 weevils remained alive and active.
92	*Calandra oryzae*	77·11	20·69	2·20	0–3 mins.	6	4·5° C.	8·5° C.	1° C.	77·24	20·38	2·38	1	After 4 hours no sign of revival. After 24 hours 1 weevil alive but feeble. After 48 hours 1 weevil still alive but very feeble.

TABLE XIV—*continued.*

No. of Experiment.	Species of Weevil.	Percentage Composition of Gases at the Time of Sealing.			Time till all Weevils became Motionless.	Period of Incubation (in days).	Temperature during Period of Incubation.			Percentage Composition of Gases at Time of Opening.			No. of Revivals alive at the End of 48 Hours' Incubation.	Observations on Weevils during Incubation to Test for Revival.
		CO_2.	O_2.	N (by diff.).			Av.	Max.	Min.	CO_2.	O_2.	N (by diff.)		
93	*Calandra oryzae*	78·74	4·93 Air	16·33	0–3 mins.	6	4·5° C.	8·5° C.	1° C.	78·03	4·85	17·12	0	After 2 hours 1 weevil was alive and walking about and 2 showed feeble movement. After 21 hours all weevils were motionless and after 48 hours no movement could be seen.
94	*Calandra granaria*	99·0	—	—	0–5 mins.	6	12·5° C.	14° C.	9° C.	99·73	—	—	94	After about 2 hours several weevils moving their legs. After 3½ hours 99 weevils were alive, but many lying on their backs. After 48 hours 94 weevils were alive, walking about and some feeding, and after 5 days 81 weevils were still alive and active and some had been feeding.

95	*Calandra granaria*	77·39	21·20	1·41	0–5 mins.	6	12·5° C.	14° C.	9 C.	81·59	16·20	2·21	24	After about 2½ hours a few weevils were moving their legs. After 3 hours 23 weevils were alive, but mostly on their backs. After 21 hours 32 weevils were alive but many still feeble. After 48 hours 24 weevils were alive but not feeding. After 5 days 14 weevils were alive, walking, and some had been feeding.

These Tables again show quite clearly the lethal effect of carbon dioxide, but their chief interest consists in the demonstration of the fact that pure carbon dioxide is decidedly less fatal in its effects than is carbon dioxide with an admixture of oxygen. Thus, at 30–31° C., after being sealed up for 20 hours in pure CO_2, ten *Calandra oryzae* all recovered (Experiment 90), whereas with an admixture of only 0·77 per cent. of oxygen and 21·34 per cent. of nitrogen only five out of ten made a partial recovery (Experiment 89), and when the percentage of oxygen was still higher there were no recoveries at all. Comparing Experiments 91 and 92, in which 100 *Calandra oryzae* were sealed for 6 days at lower temperatures, it will be seen that a similar result was obtained. but from Experiment 95, in which 100 *Calandra granaria* were kept sealed, also at a low temperature, it would appear that an admixture of about 21 per cent. of oxygen is less fatal for this species.

It would seem that pure carbon dioxide acts immediately (within a very few minutes) as a narcotic, and that in the absence of oxygen the insects may remain in a state of suspended animation for a long period without losing the power of recovery.

In order to investigate this phenomenon more thoroughly further experiments were made as shown in Tables XV and XVI.

TABLE XV.—Survival Period of ten *Calandra oryzae* in Pure Moist Carbon Dioxide at 30–31° C.

No. of Experiment.	Percentage of CO_2 at the Time of Sealing.	Time till all Weevils became Motionless.	Period of Incubation (in Hours).	Percentage of CO_2 at the Time of Opening.	No. of Revivals Alive at the End of 48 Hours' Incubation.	Observations on Weevils during Incubation to Test for Revival.
96	99·91	0–3 mins.	18¼	99·87	10	—
97	100·00	0–3 mins.	26	99·87	10	The weevils showed no sign of movement in 1 hour, but after 17 hours they were all alive, some feeding and one pair copulating. At the end of 65 hours they were all alive.
98	99·55	0–3 mins.	42	99·33	9	After 1½ hours one weevil showed feeble movements of its legs. After 48 hours nine weevils were alive, some feeding, and one was dead.

TABLE XV—*continued.*

No. of Experiment.	Percentage of CO_2 at the Time of Sealing.	Time till all Weevils became Motionless.	Period of Incubation (in Hours).	Percentage of CO_2 at the Time of Opening.	No. of Revivals Alive at the End of 48 Hours' Incubation.	Observations on Weevils during Incubation to Test for Revival.
99	99·58	0–3 mins.	48	99·68	1	After 4½ hours two weevils were feebly moving their legs. After 21 hours six weevils were alive, but lying on their backs. After 48 hours only one weevil was alive and walking about, the rest being dead.
100	99·91	0·3 mins.	50	99·80	2	After 3 hours one weevil was feebly moving its legs. After 5 hours three weevils were alive, but feeble. After 25 hours eight had recovered, but were still very feeble. After 48 hours only two were alive, and after 94 hours these also were dead.
101	100·08	0–3 mins.	72	99·79	0	In 2 hours no sign of movement. In 48 hours no sign of revival though examined frequently.

TABLE XVI.—Survival Period of 100 *Calandra oryzae* and 100 *C. granaria* in Pure Moist Carbon Dioxide at low Temperatures.

No. of Experiment.	Species of Weevil.	Percentage of CO_2 at the Time of Sealing.	Time till all Weevils became Motionless.	Period of Incubation (in Days).	Temperature during Period of Incubation.			Percentage of CO_2 at the Time of Opening.	No. of Revivals alive at the end of 48 hours' Incubation.	Observations on Weevils during Incubation to Test for Revival.
					Av.	Max.	Min.			
102	*Calandra oryzae*	99·8	0–3 mins.	6	7·5° C.	13° C.	4° C.	99·73	79	After 1 hour several weevils showed movement of their legs. After 1½ hours several were walking about. After 19 hours 87 weevils were alive and active, the rest being apparently dead. After 48 hours 79 weevils were alive and some were feeding, and after 67 hours 72 weevils were still alive and some feeding.
103	*Calandra oryzae*	99·9	0–3 mins.	13	5·5° C.	13° C.	1° C.	100·2	13	After about 1 hour a few weevils were moving their legs. After 24 hours 26 weevils were alive and walking about. After 48 hours only 13 weevils were alive. After 67½ hours 2 weevils were alive, and after 91½ hours all were dead.

104	*Calandra granaria*	99·0	0–5 mins.	6	12·5° C.	14° C.	9° C.	98·73	94	After about 2 hours several weevils were moving their legs. After 3½ hours 99 weevils were alive, but many on their backs. After 48 hours 94 weevils were alive and walking about and some feeding, and after 5 days 81 weevils were still alive, active, and some had been feeding.
105	*Calandra granaria*	99·39	0–5 mins.	13	12° C.	16·5° C.	8° C.	98·1	Between 15 and 30	In 3 hours no sign of revival. After 19½ hours 30 weevils were alive, but very feeble. After 67½ hours 15 weevils were alive, active, and some were feeding. After 7 days 5 weevils were still alive, active, and some had been feeding.

The narcotic effect of carbon dioxide upon weevils has already been noticed by Cole (1906) and by Barnes and Grove (1916), and it is interesting to note in this connection that carbonic acid gas was used in medicine as an anæsthetic as far back as 1858,* but the fact that pure carbon dioxide is actually less poisonous in its effects than carbon dioxide with a moderate admixture of oxygen appears to be entirely new to physiologists. We would suggest that the explanation of this phenomenon is that even a small amount of oxygen serves to keep the metabolism going sufficiently to enable the carbon dioxide to exert its poisonous effect, while in the complete absence of oxygen metabolism is entirely suspended.

Tables XV and XVI show that the insects may revive after being kept in pure moist carbon dioxide at a temperature of 30–31° C. for as much as 42 hours, and for at least six days at low temperatures. Some recovered after as much as 13 days sealing, but the majority of these only lived for a few days after recovery. It frequently happened that weevils recovered temporarily after treatment with pure carbon dioxide but subsequently succumbed, and we are not in a position to say how far the recovery was really permanent, though the notes appended to the tables indicate that it was so in some cases.

The effect of the pure carbon dioxide upon the weevils is almost instantaneous and they remain quite motionless during the whole period of treatment. Barnes and Grove (1916) experimented with pure dry carbon dioxide and also found that the lethal effect increases with the temperature. We ourselves used moist carbon dioxide in order to eliminate the possible effects of desiccation.

8. SUMMARY OF RESULTS GIVEN IN PART III.

(1) Grain insects sealed up in air-tight vessels, with or without wheat, succumb as soon as the oxygen has been used up, a corresponding amount of carbon dioxide being produced.

(2) The only gases present in such sealed vessels, under normal conditions, are oxygen, nitrogen and carbon dioxide.

(3) The amount of carbon dioxide given off by live wheat in air-tight vessels varies directly with the moisture content and the temperature.

(4) As regards moisture content there is a critical point, above which the production of carbon dioxide by wheat suddenly increases very greatly. This critical point varies slightly with the temperature. For the temperatures and wheats investigated it lies between 13·25 and 16·95 per cent.

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* *Vide* Oranam, M, abstracted in half-yearly abstract of the Medical Sciences, Vol. XXVIII, July–December, 1858. We are indebted to Dr. Shaw-Mackenzie for calling our attention to this reference.

(5) Above the critical point of moisture content wheat stored in air-tight receptacles very soon renders itself immune to the attacks of grain insects, but below this point it takes a comparatively long time to do so. Data are given in the appropriate places.

(6) The amount of oxygen absorbed by live wheat of low moisture content is greater than the amount of carbon dioxide given off.

(7) At about 30° C., 100 *Calandra oryzae* give off about 29·5 mg. (nearly a fifth of their own weight) of carbon dioxide in 24 hours, and at 20–21° C. only about 9·38 mg.

(8) Weight for weight, *Calandra granaria* gives off rather less carbon dioxide than *C. oryzae*, which is to be accounted for by its less active habits.

(9) The respiratory quotient for *Calandra oryzae* is about 0·773 and for *C. granaria* about 0·815, indicating that the respiratory processes of these insects are perfectly normal.

(10) The complete absence of oxygen is alone sufficient to kill weevils, without taking into account the presence of carbon dioxide, though they are able to remain alive for a considerable time when only small percentages of oxygen are present.

(11) The extent to which weevils are able to make use of oxygen in sealed vessels depends upon the percentage of that gas initially present.

(12) Carbon dioxide exerts a poisonous effect upon weevils apart altogether from the question of diminished oxygen pressure. Thus at 30–31° C. *Calandra oryzae* was killed in less than 12 days in an atmosphere containing from 14·08 to 22·56 per cent. of CO_2, though 13·88 per cent. of O_2 still remained.

(13) Pure (moist) carbon dioxide is less fatal in its effects than carbon dioxide with a small admixture of oxygen.

(14) Pure (moist) carbon dioxide acts almost instantaneously as a narcotic, under the influence of which weevils may remain motionless for a long time without losing their power of recovery.

9. General Discussion on the Efficacy and Advantages of Air-tight Storage for Cereals.

In the three parts of this Report and in our supplementary Reports on the Occurrence of Live Insects in Tins supposed to be Hermetically Sealed (1919) and on the Prevention of Heating in Wheat by means of Air-tight Storage (1919) we have brought forward a large amount of evidence which seems to indicate that the most satisfactory method for the storage of grain in large quantities and for long periods is in air-tight silos or granaries. It is, no doubt, highly desirable that, as a sequel to our laboratory experiments, the practicability of this method should be tested on a larger scale, though, as a matter of fact, the native Indian and Maltese experience, quoted in the first of our Reports, goes a long way to establish this point.

We have pointed out that much misconception has existed in the past as to the power of grain insects to resist absence of ventilation, but that the general belief in this power, shared even by professional entomologists, rested entirely upon inaccurate observation, and that grain-insects, like all ordinary animals, rapidly succumb when deprived of oxygen.

We have shown that both wheat and insects consume oxygen and produce carbon dioxide. Under normal conditions it is no doubt the consumption of the oxygen that is directly responsible for the death of the insects, though the carbon dioxide, if present in sufficient quantities, will destroy them by its poisonous effects.

We had hoped, at the commencement of our investigations, that we might have been able to furnish a series of data from which it would be possible to calculate with some exactness the time requisite to render the wheat in an air-tight silo of given dimensions and under given conditions immune from the attacks of insects by the normal consumption of oxygen and production of carbon dioxide, *i.e.*, without the aid of any changes in the atmosphere brought about by artificial means. In this, however, we have only succeeded to a very limited extent, partly because the rate of oxygen consumption and carbon dioxide production varies so greatly with the conditions of temperature and moisture and partly because of the difficulty of determining, even approximately, the number of insects which may happen to be present in the wheat.

Unfortunately, the amount of carbon dioxide produced by the wheat, and the correlated oxygen consumption, are comparatively small until a somewhat high moisture content is reached. It remains to be determined what is the limit of safety, as regards moisture content, for the air-tight storage of grain, for although we have proved that the much dreaded "Heating" cannot occur under these conditions, there is still the question of anaërobic fermentation to be taken into account. There is abundant evidence to show, however, that carbon dioxide does accumulate in large quantities in air-tight granaries in actual use in India and Malta, and that the wheat remains in good condition in these granaries for years.

The question to which we should have liked to give a more definite answer may be stated as follows. Supposing that an infected sample of wheat (or other grain) were placed in air-tight storage, could it be seriously damaged by the insects before these were killed? We think not, for if only a few insects were present these could not do much damage in the time available, while if many were present they would all be killed in a very short time as a result of their own oxygen consumption and carbon dioxide production, apart altogether from the question of the vitiation of the atmosphere by the grain.

Of course the length of time for which the insects could survive would depend both upon the number of insects present and upon the amount of air in the granary, and it is obviously desirable that the granary should always be kept as completely filled as possible. Nevertheless, it is astonishing to see how rapidly the insects, if numerous, succumb even in the presence of a relatively very large air-space. If a receptacle is only half filled with very badly infected wheat and sealed up, all the insects may become perfectly motionless within 24 hours,* and in this connection it must be remembered that a large volume of air also exists between the grains, amounting roughly to about 38 per cent. of the total volume occupied by the wheat.

In order to gain some more precise information with regard to the influence of the air-space upon the duration of life of the weevils, the series of experiments shown in the accompanying Table (XVII) were carried out. For the purpose of these experiments a sample of wheat (No. 1 North Manitoba), known to be infected with larvae and pupae of *Calandra oryzae*, but from which all loose adults had been removed, was employed. An examination of the sealed wheat at the close of the experiments showed that from 31 to 43 per cent. of the grains (the number varying in the different sub-samples) had been infected. Each sub-sample, consisting of 100 grains or "kernels" selected at random from the well-mixed main sample, was sealed up with a known volume of air, varying progressively, and including the space between the grains. The experiments were conducted at two temperatures, viz., 30–31° C. (the temperature of the original culture) and 18–23° C. (room temperature). For each experiment there was an unsealed control, and all the experiments were commenced on July 5th, 1918.

* As shown by an actual experiment.

Table XVII.—Effect of Sealing 100 Grains of Weevil-infected Wheat in Varying Air-Space.

(*a*) For 14 days at 30–31° C.

No. of Experiment.	Approximate Air Space (in c.c.).	Percentage Composition of Gases at the Time of Opening.			Number of Adult Weevils which had Emerged from the Grains at the End of the Experiment.		Number of Larvae, Pupae and Adults found inside the Grains in the Sealed Flasks at the End of the Experiment.					
							Larvae.		Pupae.		Adults.	
		CO_2.	O_2.	N (by diff.).	Live.	Dead.	Live.	Dead.	Live.	Dead.	Live.	Dead.
106 Control	41·6 —	18·45 —	1·81 —	79·74 —	0 27	0 0	0 —	24 —	0 —	9 —	0 —	1 —
107 Control	78·0 —	17·18 —	3·31 —	79·51 —	0 21	1* 1	3 —	27 —	0 —	5 —	1 —	6 —
108 Control	118·8 —	15·71 —	4·70 —	79·59 —	0 37	0 0	6 —	29 —	0 —	0 —	2 —	1 —
109 Control	273·5 —	18·61 —	1·70 —	79·69 —	0 13	3 0	2 —	31 —	0 —	0 —	1 —	2 —

(*b*) For 32 days at Room Temperature (18–23° C.).

110 Control	46·8 —	18·69 —	1·77 —	79·54 —	0 21	0 2	10 —	16 —	1 —	0 —	0 —	5 —
111 Control	77·0 —	18·14 —	2·11 —	79·75 —	0 23	0 0	9 —	17 —	2 —	0 —	0 —	11 —
112 Control	130·0 —	16·51 —	4·09 —	79·40 —	0 25	0 0	9 —	14 —	3 —	0 —	0 —	5 —
113 Control	270·0 —	18·48 —	1·98 —	79·54 —	1 25	3 2	18 —	13 —	0 —	4 —	0 —	4 —

---

* Half inside a grain of wheat.

This Table demonstrates clearly the efficiency of hermetical sealing in destroying weevils even when a relatively very large air-space is present. With 273·5 c.c. of air to 100 grains of wheat, only three insects remained alive out of a total of 39 (including all stages) at the end of 14 days, at a temperature of 30–31° C. (exp. 109). At room temperature a parallel experiment (113) resulted in 19 insects remaining alive out of a total of 43 at the end of 32 days, but in both cases the percentage of carbon dioxide had been raised to between 18 and 19, and that of the oxygen diminished to less than 2, so that it is quite certain that the remaining insects would have succumbed very shortly.

Experiments 109 and 113, each with the maximum air-space, were the only two in which live adults actually emerged from the grains in the sealed vessels, and of these all but one had succumbed before the close of the experiments.

A comparison of the results obtained in the sealed vessels with those given by the controls shows, in cases of prolonged survival, a marked retarding influence exerted by hermetical sealing upon the development of the insects. This is particularly evident in the case of experiment 113, in which, at the end of 32 days, 18 live larvae were still present in the sealed vessel, and only eight insects had reached the adult condition, while in the control 27 adults were found.

In none of the sealed vessels did more than 4·7 per cent. of oxygen remain at the close of the experiment, the percentage of carbon dioxide ranging from 15·71 to 18·69. It is very interesting to observe, as compared with Tables I to III, that the percentage of nitrogen, as estimated by difference, remained almost unaltered at the close of each experiment of this series. This seems to indicate that the respiratory quotient of the larvae and pupae is higher than that of the adults, probably being in the neighbourhood of 1.

The above experiments indicate that a useful test for concealed weevilling could be made by sealing the wheat for a short period. In one of our very early experiments we were at a loss to understand why a particular sample of Australian wheat containing only 11–13 per cent. of moisture, and apparently quite sound, gave off so much CO_2. After incubation the wheat was examined and live weevils were found to have emerged from the grains, which immediately supplied the answer. The following test, which could be quickly applied to representative samples of cargoes of grain arriving at the docks, would serve at once to determine whether such grain could be safely stored in this country in the ordinary way, or should be put into air-tight storage. 100 grammes of the well-sampled wheat might be hermetically sealed in a suitable flask fitted for analysis, and incubated for seven days at 20–22° C. At the same time a moisture determination should be carried out. If the moisture content of the wheat was less than 15 per cent., and the quantity of CO_2 determined by analysis was above, say 4 mgs., the wheat would be viewed with grave suspicion as to concealed weevilling. The above figures (see Table IV) are only given by way of example, since the quantity of wheat, the temperature, and the period of sealing could easily be adapted to meet the requirements for the quick handling of the grain, and the variety of wheat might also have to be taken into consideration.

The advantages of air-tight storage may be briefly summed up as follows :—

(1) It sterilises the grain by destroying insects in all stages, or other vermin which may be present.
(2) It prevents, absolutely, the access of insects and other vermin.
(3) It prevents even grain with a high moisture content from becoming mildewed, as we have shown by experiments not described in these reports.
(4) It prevents even grain with a high moisture content from heating (but it does not prevent the development of acidity, due presumably to anaërobic fermentation, if the moisture content is excessive).
(5) It prevents the absorption of moisture from the atmosphere, so that grain if stored dry will remain dry.
(6) It saves labour and expense by doing away with the necessity for turning the grain over or running it from one silo into another in order to prevent heating.

There can be no doubt that if large air-tight silos were erected at the ports in the great grain-growing countries the grain could be stored therein, if necessary for years, without any risk of deterioration, at any rate so far as its bread-making qualities are concerned. Indeed, Professor Zammitt, quoted in the first part of these Reports, informs us that the bread-making quality of the grain is actually improved by this treatment, though the germinating power is affected if the grain is stored for more than two years. Howard (1915), however, states that Indian wheat thoroughly dried in the sun at harvest time and then immediately put away in air-tight receptacles can be preserved for long periods without injury to its subsequent germination.

One of the obvious advantages of such a method of storage is the possibility of regulating shipments, by doing away with the necessity for getting the grain away as soon as possible after the harvest. Again, if no grain were allowed to be shipped until it had been in air-tight storage for a sufficient time—a time which could only be determined by experience, but which probably need not exceed a very few months, depending upon the rate of accumulation of carbon dioxide—the risk of weevilling on board ship, which is at present very serious, would be minimized, for such weevilling could only be due to re-infection, which ought to be preventable by proper precautions as to cleanliness and disinfection of the ship. It might even be desirable to ship the grain in air-tight tanks, but this ought not to be necessary. At present much grain is landed in this country in a badly weevilled condition, but we understand that the grain-merchants here protect themselves by simply "knocking it off the price."

There are, of course, many methods for cleaning weevilly wheat, and at least one method—by the application of heat—has proved successful, we understand, in destroying the weevils, but, so far as we know, the only method which combines the absolute sterilisation with the prevention of re-infection of grain is air-tight storage.

Of course the initial cost of erecting the necessary silos would be very high, but when we consider that even before the war the annual loss from weevilling throughout the world amounted to many millions of pounds sterling, it seems probable that this outlay would be recouped in a comparatively short time.

In conclusion we would venture to point out the importance of air-tight storage as a means of maintaining a reserve of cereals in case of war, or in case of failure of crops. It has been suggested that the proper method of providing against such shortage as we have suffered from during the late war is by encouraging the farmers of this country to grow more wheat, but already we are told that the acreage under wheat has very largely diminished since the armistice, and if this is the case a large reserve in this country seems to be imperative.

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TABLE OF CONTENTS.

Page

I. Introductory Remarks—

A.—Historical 3

B.—Material and Methods 4

C.—Notes on Life-Histories and Bionomics 10

II. Statistics of Multiplication under various conditions, and Discussion thereof—

A.—*Calandra oryzæ* (Tables I.—VI.) 13

B.—*Calandra granaria* (Tables VII.—XII.) 24

C.—Comparative Fertility of *Calandra oryzæ* and *C. granaria* (Table XIII.) 33

D.—*Rhizopertha dominica* (Table XIV.) 37

III. Temperature Limits for the Life of the Insects 39

IV. Conditions necessary as regards Moisture (Table XV.) ... 45

V. Effects of the Insects upon Wheat 48

VI. Summary of Results 50

VII. List of Literature referred to 51

REPORT ON THE VITALITY AND RATE OF MULTIPLICATION OF CERTAIN GRAIN INSECTS UNDER VARIOUS CONDITIONS OF TEMPERATURE AND MOISTURE.

By ARTHUR DENDY, D.Sc., F.R.S., Professor of Zoology in the University of London (King's College), and

H. D. ELKINGTON, B.Sc., F.I.C.

I. Introductory Remarks.

A.—*Historical.*

We have found, in the literature of the subject, very little reliable information as to the rate of multiplication of grain insects under various conditions, although no doubt it is generally understood that, within certain limits, their increase is promoted by warmth and moisture. Cotes (1888) gives the following translation of a passage from Menault's " Insectes Nuisibles à l'Agriculture " (Paris, 1886) :—" Bory de Saint Vincent says that, according to Dégur's calculation, a single female [*Calandra granaria*] in one year can produce 23,600 individuals ; another estimate gives 75,000 individuals as the offspring of twelve pairs of weevils in a hectolitre of grain, each of which would consume three grains for its own subsistence, or about 12 per cent. Other naturalists confine their estimate of the offspring of twelve pairs to about 6,000." These are, of course, but vague estimates, and apparently they leave out of account the very important factors of temperature and moisture, but they serve to indicate the differences of opinion prevailing on the subject, while all seem to be agreed that the rate of increase is very high.

For some figures obtained by actual counting we are indebted to Hooper (1913), but his results are vitiated by the fact that a large number of weevils were removed during the course of the experiment in order to simplify the counting of those that were left to breed. He worked with *Calandra oryzæ* in India, during warm weather, and took precautions to keep the cultures moist. His estimate of a 60-fold increase in three months is admittedly below the mark, and we ourselves have obtained a 700-fold increase in four months with the same species.

Cole (1906) found 80° F. the most suitable temperature for cultures of *Calandra granaria* and apparently also for *C. oryzæ*. He tells us that cold is very fatal to both species, and that he lost the whole of his large stock of adult beetles owing to a failure of the heating apparatus during one frosty night. We may say at once that this latter statement is hardly in accordance with our own experience. Concerning the upper temperature limit it was shown more than eighty years ago by Mills (1836) that a temperature of 130–140° F. is fatal to corn weevils. This result has since been extended to other species of grain insects, and forms the basis of the well-known American system of curing insect-infested grain by heating.

Cole (1906) also demonstrated the importance of moisture for the existence of grain-weevils, but reliable information as to the amount of moisture necessary is still lacking. Nevertheless it may be regarded as safely established that a very low moisture content in the grain is unfavourable to weevils, and the importance of getting the grain as dry as possible before storing by ordinary methods is fully recognised, both from the point of view of weevilling and heating.

In 1911 an extremely interesting paper on the life-history of the Rice-Weevil (*Calandra oryzæ*) in Alabama was published by Messrs. Hinds and Turner in the "Journal of Economic Entomology." This paper is remarkable for the information which it gives as to the habits and life-history of the weevil in the cornfields, a subject on which hardly anything was previously known.

Another recent publication of much importance is the memoir by Messrs. Barnes and Grove (1916) on "The Insects attacking Stored Wheat in the Punjab," wherein valuable information is given as to the life-histories of the most important species and as to methods of extermination, but even this paper contains but little information with regard to the actual rate of multiplication.

B.—*Material and Methods.*

We should like to say at the outset that under more favourable conditions this investigation might have been carried out in a more satisfactory manner. The work, which should of course have been continuous, has been greatly interrupted by illness and by pressure of other business. Moreover, we have had to learn our methods by experience, as the work has gradually grown under our hands. Were it possible to start afresh in the light of this experience, we should be able to plan it all out beforehand, with a pretty accurate knowledge of what would be required. Nevertheless we are able to furnish a large number of data as to the rate of multiplication and conditions of life of the insects studied, and we hope that our failures as well as our successes will help towards the evolution of a really satisfactory method of studying such problems. By presenting our statistical results in a tabulated form we have endeavoured to save space and facilitate comparison of one culture with another.

All our cultures have been made with wheat, and our thanks are due especially to the Royal Commission on Wheat Supplies and to Messrs. J. and H. Robinson, of the Deptford Bridge Flour Mills, for the necessary material. Messrs. Robinson have not only treated us most generously in this respect at a time when wheat was none too plentiful, but they have also given us from time to time a great deal of valuable information. The wheat used in the great majority of cases was a hard Canadian variety known as No. 1 North Manitoba. A considerable number of cultures were made in soft English wheat, and only a few in other varieties, as specified in the Tables.

As the moisture content of the wheat is generally understood to have considerable influence on the behaviour of grain insects, this must, as far as possible, be taken into account. Wheat is, however, a very hygroscopic substance, readily absorbing or giving off moisture according to the state of the atmosphere,* so that its condition in this respect is liable to great changes during the course of an experiment. It is of some importance, nevertheless, to know the moisture content at the beginning of the experiment. This may be learned approximately from the following Table, which shows the moisture content on different dates of the samples used. It will be observed that this varies with the season. The figure to be taken in any particular case is of course that for the date which corresponds most nearly with the date of commencement of the culture.

Table showing the Wheats used and their Moisture Content on different Dates.

Sample No.	Variety.	Moisture Content Percentage on given Dates.							
		3.4.18.	19.6.18.	16.7.18.	6.8.18.	2.9.18.	14.10.18.	22.1.19.	10.2.19
13A	No. 2 Red Winter	12·2	—	—	—	—	—	—	13·1
14A	No. 2 Club Calcutta	11·2	—	—	—	—	—	—	12·3
18A	Australian	11·4	—	—	—	—	—	—	12·7
20A	No. 1 North Manitoba	11·7	—	—	—	—	—	—	12·8
21A	Rhodesian	11·5	—	—	—	—	—	—	—
22A	No. 1 North Manitoba (uncleaned)	11·9	—	—	—	—	—	—	12·5
23A	No. 1 North Manitoba (cleaned)	11·9	—	—	—	10·2	—	12·8	—
24A	English (mixed)	....	17·2	15·9	15·6	14·3	13·3	14·2	—
33A	Pusa 4	—	10·6	—	—	—	—	—	—
36A	English (Victor)	—	12·8	—	—	—	—	—	—

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* This appears to be well known in the trade, yet Barnes and Grove [1916] say "It appears questionable if wheat is capable of taking up moisture from a moist atmosphere under ordinary conditions of storage."

The moisture percentages given in the above Table (and in that which follows) were determined in the usual way by drying 10 grams of the wheat in an electric oven at a temperature of 100–102° C. for 48 hours. We have also made a number of cultures with wheat artificially dried in this manner (*see* Tables VI, XII).

In order to get some idea of the actual changes as regards moisture content undergone by the wheat while in the incubators we have made a number of experiments with wheat free from insects. The results are shown in the following Table, but it must be remembered that the presence of insects in a culture must itself have a considerable influence upon the moisture content, and we shall refer later on to the accumulation of moisture when the wheat begins to decompose.

Table showing Changes in Moisture Content of Wheat in Incubators.

(In each case 100 grams of the wheat were placed in a glass cylinder covered with cambric.)

Sample No.	Incubator No.	Average Temperature. ° F.	Atmospheric Condition.	Moisture Content Percentage on given Dates.			
				22.1.19.	10.3.19.	7.4.19.	22.4.19.
23A	1	87	Moist	12·80	12·20	12·15	12·25
"	2	79	"	"	12·90	13·60	13·70*
"	3	70	Dry	"	10·37	9·80	9·7
"	4	70	Moist	"	12·55	12·15	12·60†
"	(Room cupboard)	50	—	"	—	—	12·75
24A	1	87	Moist	14·20	11·90	12·65	12·70
"	3	70	Dry	"	10·20	9·95	9·90
"	4	70	Moist	"	13·50	12·85	12·70†
"	(Room cupboard)	50	—	"	—	—	13·65‡

* Large number of mites present and grain slightly caked.
† Slightly mitey.
‡ Fairly mitey.

The first of the foregoing Tables shows very clearly the hygroscopic character of the wheat. Even in the ordinary atmosphere of the laboratory, at room temperature, it gives up moisture during the summer and autumn and absorbs it during the winter months.

The second Table shows a great difference between the dry and moist incubators as regards the effect upon the wheat. In the former the moisture content sank to a little less than 10 per cent. both in the case of the fairly dry hard Canadian and the moist, soft English wheat, while in the moist incubators it never sank below 12·25 per cent., and never rose or remained higher than 13·70 per cent. The Table seems to indicate that the moisture content of the wheat at any given temperature is determined by the humidity of the atmosphere, a state of equilibrium being established between the wheat and the surrounding air. Hence, even in a moist incubator, the wheat does not become excessively damp, as we have repeatedly observed, yet always contains sufficient moisture to enable weevils to flourish. The fact that mites appeared in considerable numbers in some of the samples, as shown in the Table, may be responsible for some increase in the moisture content of the wheat above the normal.

In all breeding experiments it is of course necessary to make certain that the wheat employed is not already infected. It sometimes happens that a sample which is supposed to be quite free from insects is found on incubation to be really contaminated. A very good example of this was described in the second part of our Report on the Effect of Air-tight Storage upon Grain Insects (1918) (Experiment E), where a supposed clean sample of Indian wheat (14A) yielded, on prolonged incubation, a good culture of *Rhizopertha dominica.* In the same way another sample (No. 1 Club Bombay), supplied to us for the purposes of our experiments, proved to be useless on account of the presence in it of both *Rhizopertha dominica* and *Calandra oryzæ.* On the other hand, the Canadian (20A, 22A, 23A) and mixed English (24A) wheats used in the great majority of our cultures, showed on incubation no indication of the presence of insects, and may safely be assumed to have been pure in this respect. The Rhodesian sample (21A), the sample of No. 2 Red Winter (13A), and the Australian sample (18A), with which a few of our cultures were made, also proved on incubation to be insect-free. It was not thought necessary to test 33A and 36A, of which only very small quantities were available, the former being used only in two cultures (9, 28) and the latter in one (29). Sample 14A (No. 2 Club Calcutta), though known to be slightly infected with Rhizopertha, was used for two cultures of weevils (7, 67) included in our Tables, and no Rhizopertha made their appearance in either.

Four incubators were used for our cultures. Nos. 1 and 2 were Hearson's Biological Incubators, No. 3 was a small egg incubator, also by Hearson; No. 4 was really an embedding oven, but served very well for its new purpose. The temperature of No. 1 was maintained very uniformly at 86–89° F., the idea being to reproduce the Indian summer temperature, but it may have been a little too high, as Barnes and Grove give 86° F. as an average warm-weather temperature. No. 3 was intended to reproduce the English summer temperature, and kept very uniformly at about 72° F. No. 4 was kept at about the same temperature as No. 3. No 2 was maintained at an intermediate temperature ranging from 77° F. to 86° F., it being found impossible to regulate it more exactly, as this incubator was designed for a higher temperature.

Numerous cultures have also been made at room temperature. These, with the exception of No. 25, were kept in a dark cupboard in the laboratory. No. 25 was kept in the incubator room, feebly lighted.

The temperatures were recorded daily, with the exception of Sundays, and our thanks are due to Mr. H. G. Billinghurst for assistance in this respect. In the case of the varying room temperature (except for Culture 25), the maximum and minimum for the preceding 24 hours were recorded. In the Tables the average, maximum and minimum temperatures for each period of incubation have been inserted. The average for any period was arrived at by adding together all the maxima and minima recorded during that period and dividing by the number of records.

In considering the actual temperature conditions under which the insects were living in our cultures allowance has to be made for the fact that, owing to the presence of the insects (and perhaps partly to a certain amount of "heating" in the weevilled wheat), the temperature of the culture is likely to be somewhat higher than that of the incubator itself, which is the temperature recorded in our Tables. We have taken some pains to satisfy ourselves on this point by the use of pairs of standard thermometers plunged in weevilled and unweevilled wheat respectively. We have done this in Incubators 1 and 2, and recorded the readings daily for a month, during which period the greatest difference in temperature between the weevilled and the unweevilled wheat was 7° F. No doubt in large quantities of weevilled wheat a very considerable rise of temperature may occur, whereby the multiplication and activities of the weevils will be promoted.

Being aware, from the work of previous observers, that a moist atmosphere is favourable to the life and multiplication of the weevils, we endeavoured to secure this by placing open vessels of water in Incubators 1, 2 and 4, but no attempt was made to ascertain the degree of saturation of the atmosphere, and on two or three occasions the water was accidentally allowed to dry up, though we have no reason to believe that this materially affected the cultures. During the later part of the work No. 3 incubator was kept without water so as to give a comparatively dry atmosphere for comparison with the others. The experiments at room temperature were of course subject to the ordinary atmospheric changes as regards moisture.

The observations recorded in this Report are confined to the three species, *Calandra oryzæ*, *C. granaria* and *Rhizopertha dominica*, which are by far the most serious grain-pests, at any rate in our experience. All our material was originally obtained from commercial samples derived from various sources. Pure stock cultures of all three species were kept going constantly at various temperatures, and these were used for starting sub-cultures as required. In all cases, except where the contrary is stated in the Tables, the culture was started with insects which had been kept at the same temperature as the culture itself. The idea that a sudden moderate change of temperature might affect the insects did not occur to us at the commencement of the investigation, nor have we any evidence that it does so, but it is obviously desirable that any such change should be avoided as far as possible.

The cultures were put up in small glass jars, cylinders, or test-tubes, covered with cambric tied tightly round the top, which we found a perfectly satisfactory method unless they were allowed to become too crowded, when the insects would eat their way through the cambric. When it was necessary to count the number of insects, the contents of the jar were turned out into a large porcelain dish, if necessary a little at a time, and the insects carefully picked out with forceps. For this purpose a pair of forceps with flat ends, as used for handling postage stamps, was found very convenient. The insects were usually counted into small glass tubes, in fifties or hundreds. In the case of Rhizopertha, which is more easily injured than the weevils, the insects were sometimes swept into the tubes with a camel hair brush. The final results of each culture were usually, if not invariably, tested by incubation of the supposed dead, but intermediate results could not be so tested without too much disturbance of the insects and loss of time, all insects, whether alive or dead, being returned to the culture.* Hence slight discrepancies, as in Culture 49, sometimes appear in the Tables. There is usually, however, little difficulty in deciding whether an insect is alive or dead, for though the two weevils sham death very readily, they soon recover when breathed upon or placed on the palm of the hand, and require even this stimulus only in cold weather, generally resuming their activity spontaneously in a very few minutes. In the sometimes very laborious task of counting the insects we have received valuable help from Miss Ruth Courtauld and Mr. H. G. Billinghurst.

Every care was taken to ensure accuracy in our results, but absolute accuracy is rendered impossible by the well-known habit of the insects of concealing themselves in the grains. We believe, however, that they mostly emerge during the process of examination (which was usually concluded at the last count by repeated sifting), at any rate in the case of the weevils. In a few instances, where the culture was a small one, the grains were all cut open at the close of the experiment, and the insects extracted therefrom. This was done in the case of Cultures 5, 9, 29, 34, 61 and 75 (*see* Tables), and from the results obtained we conclude that an addition of about 7 per cent. should be made to the final number of live insects in the case of the two weevils, and probably considerably more for Rhizopertha, which conceal themselves much more effectually. It is obvious, therefore, that the results recorded are all minima, and that the actual rate of breeding is higher than that indicated by the Tables. It would probably be higher still in large quantities of wheat such as are stored in granaries, where the insects would be able to move on to fresh supplies as necessity arose (compare Culture 56, started with 100 weevils in 500 grams of wheat).

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* **Except in special cases as mentioned in the Tables.**

C.—*Notes on Life-Histories and Bionomics.*

A complete account of the life-history and bionomics of the insects concerned would be altogether beyond the scope of this Report, but the following brief notes are given, either as having a direct bearing upon the subject matter thereof, or as referring to interesting facts that have come to light incidentally in the course of our investigations.

The best account of the life-history and habits of *Calandra oryzæ* under natural conditions is undoubtedly that given by Hinds and Turner (1911), who show clearly that this insect is a pest in the cornfields as well as in the granary. More recently Barnes and Grove (1916) have given an illustrated description of the life-history of *Calandra oryzæ* and of *Rhizopertha dominica*, and to this work also we are indebted for much valuable information. The breeding and feeding habits of *Calandra granaria*, at any rate in stored grain, do not appear to differ materially from those of *C. oryzæ*.

The weevils (*C. oryzæ*) lay their eggs singly in minute punctures made in the pericarp of the grain, oviposition commencing about three days after mating (Hinds and Turner). The rate of oviposition depends upon the hardness of the grain, the maximum rate observed being 20 eggs in 24 hours. The female continues to lay eggs until within a few days of her death, the greatest number hitherto recorded from one female being 417. Copulation may occur repeatedly,* and may take place in both sexes within 24 hours of their emergence from the grain. The egg hatches in about three days at a mean temperature of 60–65° F., giving rise to a small, soft larva, which begins to excavate the interior of the grain, feeding upon the endosperm and assuming a very fat, clumsy shape as it grows. Hinds and Turner recognise three larval stages, occupying, on an average, 3, 4 and 9 days respectively at a mean temperature of 60–65° F. A pre-pupal stage of one day follows, and then pupation occurs, still within the grain. The average length of the pupal period is about six days in Alabama, from 6 to 14 days in India, according to the season (Barnes and Grove). The imago remains in the "kernel" for several days to harden and fully mature before attempting to escape.

The total length of time occupied by the life-cycle varies enormously according to the season. It is well known that warmth accelerates and cold retards the development. Menault (*loc. cit.*) gives 45 days as an average time for the complete cycle in *Calandra granaria*. Barnes and Grove, at Lyallpur, in India, found that for *Calandra oryzæ* the time varies from 21 days (September—October) to 124 days (December—April), development ceasing in January and the insects remaining in the larval state, presumably till April. Hinds and Turner state that in Alabama the larval period may be extended to about four months in the winter, and that many weevils hibernate in the fields, in old corn-stalks, &c. We shall show presently that a precisely similar state of things as regards *larval* hibernation, if we may so call it, occurs in this country at ordinary room temperatures with this species. At Lyallpur, the majority of the adult insects die off during the hot, dry weather, and breeding is not normally resumed till after the rains (September). In this country, at room temperature, the adults die off during the winter months, and multiply only during the warmest part of the year. *Calandra granaria*, however, is less susceptible to cold.

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* According to Hinds and Turner parthenogenesis may occur not unfrequently.

As regards the length of life of the adult weevils very little appears to be known. Fitch (1879) observes that *Calandra granaria* appears to be remarkably long lived, but the evidence for this somewhat vague statement appears to be totally inadequate, consisting in the fact that the weevils continued to live for about two years in maize, although the writer "believed" that they had not bred. Hinds and Turner tell us that the weevils cannot live long without food—in April about nine days, in May only five days, in August seven days. Where feeding can take place normally, the length of life is exceedingly variable, extending in many cases, where the winter season intervenes, to six or eight months.

Although we have not ourselves paid special attention to this point certain tentative conclusions may be derived from some of our cultures. Thus, in Culture 25 (*Calandra oryzæ*) out of 100 weevils placed in the wheat on January 5th, 1918, not more than 90 were found dead on October 5th, after a lapse of 242 days. It is hardly likely that ten dead weevils remained concealed in the grains when the examination was made. Again, in culture 55 (*Calandra granaria*), not more than 80 out of the original 100 were found dead after a lapse of 272 days. Both these cultures were kept at varying room temperature. We do not, of course, know the ages of the weevils when they were placed in the cultures, but the probability seems to be that the normal life of the adult insects of either species in this country is not less than nine nor more than 12 months. In the case of *C. oryzæ*, as we shall show later on, the adults rarely survive the winter at ordinary room temperatures.

The breeding habits of *Rhizopertha dominica* are somewhat different from those of the two weevils. The adult insect, in attacking the grain, "mills" a great deal more flour than it requires for its own consumption, and this, together with the fæcal pellets, forms a large quantity of dry dust lying amongst the grains. The eggs are laid loose amongst the grains, singly or in clusters, and Barnes and Grove have observed as many as 586 laid by a single female. The eggs hatch in the course of a few days (longer in cold weather), and the young larvæ move rapidly about amongst the grains. They are able to feed on the flour produced by the activity of the adults, but they normally bore their way into grains of which the hard pericarp has been damaged, and there complete their development, feeding upon the endosperm and pupating like the larvæ of Calandra. The time occupied by a complete life-cycle, from egg to adult, varies, according to Barnes and Grove, from 35 days (May—June) to 183 days (October—April), and the insect is said to be most active at Lyallpur from May to August. Our own results also indicate that this species is adapted to a higher temperature than either of the two weevils.

Froggatt (1918) states that *Rhizopertha dominica* does not deposit eggs in or upon wheat grains but drops them into the loose mass, and the growing larvæ do not even bore into the grains, the damage being confined to the adult beetles. We ourselves, however, are able to confirm the statement of Barnes and Grove that the larvæ enter the grains, for we have found them there on cutting grains open.

It is well known that *Calandra oryzæ* is distinguished from *C. granaria* by, amongst other things, the possession of well-developed wings, but, curiously enough, these wings seem to be very seldom, if ever, used in a state of captivity. There appears, however, from the observations of Hinds and Turner, to be no doubt that the wings are used freely in a state of nature. These investigators say that the weevils spread in the fields entirely by flight, not even crawling up the corn-stalk to reach the ear, but flying direct thereto. On one or two occasions one of us thought that he had seen this species flying in a culture jar, but careful observations directed towards this point failed to yield any positive evidence. *Rhizopertha dominica*, on the other hand, can easily be made to fly in captivity by bringing an electric light near them when they are warm and active.

Barnes and Grove (1916) have already recorded, in the case of *Calandra oryzæ*, how the insects come to the surface in large numbers when the wheat containing them is disturbed. A similar phenomenon takes place with both species when the culture jars become overcrowded and the conditions of life presumably unfavourable, the weevils then swarming in a dense black mass on top of the grain. At such times they frequently escape by eating their way through the cambric cover of the jar, but they never do this under ordinary circumstances. Only in the case of one culture (No. 76), where the grain had become very foul, have we known Rhizopertha to escape by eating through the cover, but this species very readily bores into corks.

Both species of weevil are negatively phototropic, as shown by the fact that when a culture is turned out into a flat dish the insects leave the grain and move away from the light. They are strongly attracted by moisture, as described in No. 3 of the Reports of the Grain Pests (War) Committee of the Royal Society (Dendy, 1918). They are also very sensitive to temperature stimuli, becoming perfectly torpid at both high and low temperatures, as described in Section III of the present Report. In cold weather it is often necessary to warm the dish on which they are being examined in order to make them leave the grain and move actively about, while in hot weather their too active movements (especially in the case of *C. oryzæ*) may be restrained by placing the dish on melting ice. Their habit of shamming death when touched has already been mentioned. In this condition their legs are folded in against the sides of the body, which assumes the form of an elongated rectangle with the snout projecting in front (the antennæ being laid close in against the snout), not really very like a dead weevil, in which the legs are usually more extended and the body curved.

In some of our stock cultures of both species numerous chalcid and proctotrupid " Flies " have made their appearance, and the investigation of these, and of their effect upon the weevils, has been handed over to Mr. E. S. Goodrich, F.R.S. It is hardly necessary to state that these hymenopterous insects, which attack the larvæ of the weevils, were not introduced with the adults into those cultures which were used for ascertaining the rate of multiplication, but they appear to be very generally present in ordinary commercial samples of weevilled wheat, both Indian and Australian.

II. STATISTICS OF MULTIPLICATION UNDER VARIOUS CONDITIONS AND DISCUSSION THEREOF.

A.—*Calandra oryzæ*.

TABLE I (*Calandra oryzæ*).—Increase in Incubators at various Temperatures, in moist Atmosphere, in normal Wheat, from Pairs taken in Copulation.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
1	23A		89	86	6.6.18	—	2	—	Started with 10 grams wheat, made up to 120 grams on 29.7.18. On 7.10.18 all loose adults removed and grain again incubated till 21.10.18, when 188 live and 112 dead adults were found.
					29.7.18	53	18	4	
					7.10.18	123	444	274	
2	24A		89	86	22.6.18	—	2	—	Started with 10 grams wheat, made up to 120 grams on 29.7.18.
					29.7.18	37	42	6	
					28.9.18	98	131	62	
					22.10.18	122	470	101	
3	21A		89	86	3.8.18	—	2	—	Started with about 10 grams wheat.
					17.9.18	45	1	4	
					9.12.18	128	39	44	
4	20A	82·5	89	74·5	23.4.18	—	2†	—	Started with 10 grams wheat, made up to 120 grams on 10.6.18. All loose adults removed on 29.7.18 and grain incubated again for 14 days, yielding 653 live and 58 dead adults.
					22.5.18	29	6	0	
					10.6.18	48	19	0	
					1.7.18	69	113	7	
					29.7.18	97	758	32	
5	23A	83·3	89	78	7.8.18	—	10‡	—	Started with 10 grams wheat. On 18.9.18 the grains were all cut across, and 13 live and 7 dead adults and 82 larvæ found in them.
					18.9.18	42	177	6	
6	23A	69	77·0	62·5	10.6.18	—	2	—	Started with 10 grams wheat, made up to 120 grams on 5.8.18.
					5.8.18	56	20	0	
					18.9.18	100	116	1	
					10.10.18	122	296	1	

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* Cultures 1, 2, 3, 4, 6 were started with insects from cultures at the incubator temperatures; No. 5 with insects from a culture at room temperature.

† On 25.4.18 and 5.5.18 the pair were again in copulation.

‡ Five pairs.

TABLE II (*Calandra oryzæ*).—Increase in Incubators at various Temperatures, in moist Atmosphere, in normal Wheat, from unsorted Individuals.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
7	14A		89	86	12.12.17	—	100	—	Started with 150 grams wheat, filled up with fresh wheat on 9.2.18.
					15.1.18	34	344	19	
					15.2.18	65	1,776	40	
8	23A		89	86	5.4.18	—	100	—	Started with 130 grams wheat. On 13.6.18 all loose weevils removed and grain again incubated till 26.6.18, yielding 177 live and 15 dead adults.
					14.5.18	39	1,160	65	
					13.6.18	69	1,308	667	
9	33A		89	86	31.5.18	—	20	—	Started with 10 grams wheat. On 1.10.18 all grains cut across, yielding 12 dead adults but no live adults or larvæ.
					9.7.18	39	21	10	
					31.7.18	61	40	36	
					31.8.18	92	82	63	
					1.10.18	123	98	86	
10	23A		89	86	13.6.18	—	100	—	Subculture of 8 started with 130 grams wheat. On 31.8.18 all loose adults removed and grain again incubated till 17.9.18, yielding 253 live adults and 135 dead.
					31.8.18	79	740	379	
11	13A	77	84	70	14.1.18	—	100	—	Started with 150 grams wheat. Removed from incubator for a few hours on 24.1.18.
					9.4.18	85	975	284	
12	23A	71	79	65·5	5.4.18	—	100	—	Started with 130 grams wheat. On 11.6.18 all loose adults removed and grain again incubated till 26.6.18, yielding 737 additional live adults.
					14.5.18	39	94	5	
					11.6.18	67	1,502	26	

* Cultures 8 and 10 were started with insects from cultures at the incubator temperatures; 12 with insects from a culture at 86–89° F. For 7, 9, 11 there is no record of origin.

Discussion of Tables I and II.

Cultures 1 and 2 show an increase of about 230-fold in about 17½ weeks at a temperature of 86–89° F. The much lower rate of increase, shown in Culture 3, at the same temperature, is probably to be attributed to constitutional lack of fertility in the individuals employed, or possibly to some disproportion arising between the two sexes. Culture 4, at an average temperature of 82·5° F., gave the most remarkable increase which we have obtained. Taking into account the results of the final incubation, it shows an increase of about 700-fold in 16 weeks, with a very low mortality. We imagine this temperature to be near the optimum for the breeding of *Calandra oryzæ*. Culture 6, at an average temperature of 69° F., shows an increase of only about 150-fold in 17½ weeks. These results were obtained from pairs taken in copulation, which is evidently a far more reliable method of determining the rate of increase than that employed in Cultures 7–12 (Table II), which were started with comparatively large numbers of unsorted individuals in a small quantity of wheat, and give very irregular results. This irregularity is doubtless to be attributed partly to disproportion between the sexes in any population picked out at hazard. The high rate of mortality in most of the cultures, especially in the later stages, indicates unfavourable conditions, though what these are it is hard to say, for Culture 4 shows a mortality of only about 6·5 per cent. in 16 weeks, although the grain became very foul, so that it would scarcely seem that mere fouling of the grain is sufficient to account for it. The very low rate of increase shown in Culture 9 may perhaps be attributed to the unusual dryness of the wheat at the commencement of the experiment, but the question of the effect of moisture upon the weevils will be discussed later on (*see* Section IV).

It is clear from these Tables that, given the necessary warmth and moisture, *Calandra oryzæ* goes on breeding all the year round. Although we have made no special effort to determine the period which elapses from the date of oviposition to that of emergence of the imago from the grain, a certain amount of information may be derived from our experiments. Culture 7 shows that at about 88° F. it is not more than 34 days, while Culture 4 shows that at an average temperature of 82·5° it is not more than 29 days, periods which fall well within the limits given by Barnes and Grove.

TABLE III (*Calandra oryzæ*).—Increase at varying Room Temperature, in normal Wheat, from Pairs taken in Copulation.*

Culture No.	Wheat used.	Temperature.			Culture Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
13	23A				10.6.18	—	2	—	Started with 10 grams wheat.
		66·5	80	60	17.9.18	99	1	1	
14	24A				1.7.18	—	2	—	Started with 10 grams wheat. Weevils kept out of wheat till 3.7.18.
		67·5	80	66·5	17.9.18	78	11	0	
		58·5	66	52	3.10.18	94	32	1	
		53·5	59	48	7.12.18	159	53	4	
		50·5	58·5	41	17.1.19	200	43	11	
		50	55·5	38·5	3.4.19	276	0	56	
15	24A				1.7.18	—	2	—	Started with 10 grams wheat. Weevils kept out of wheat till 3.7.18.
		67·5	80	66·5	17.9.18	78	5	0	
		58·5	66	52	3.10.18	94	11	0	
		53·5	59	48	7.12.18	159	20	3	
		50·5	58·5	41	17.1.19	200	17	9	
		50	55·5	38·5	3.4.19	276	0	25	
16	24A				1.7.18	—	2	—	Started with 10 grams wheat. Weevils kept out of wheat till 3.7.18.
		67·5	80	66·5	17.9.18	78	0	2	
		58·5	66	52	3.10.18	94	0	2	
		53	59	41	6.1.19	189	0	2	
		48·5	55·5	38·5	3.4.19	276	0	2	
17	23A				4.7.18	—	2	—	Started with about 15 grams wheat.
		67·5	80	66·5	17.9.18	75	17	1	
		53·5	66	48	7.12.18	156	34	8	
		50·0	58·5	38·5	3.4.19	242	0	41	

TABLE III—*continued.*

Culture No.	Wheat used.	Temperature.			Culture Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
18	23A	67·5	80	66·5	4.7.18	—	2	—	Started with about 15 grams wheat.
		53·5	66	48	17.9.18	75	2	1	
		50	58·5	38·5	7.12.18	156	3	2	
					3.4.19	273	0	5	
19	23A	67	80	60	31.7.18	—	2	—	Started with about 10 grams wheat.
		63	66	52	17.9.18	48	2	0	
		54	59	48	1.10.18	62	2	0	
		50	58·5	38·5	7.12.18	129	0	3	
					3.4.19	246	0	5	
20	21A	65	80	58	3.8.18	—	2	—	Started with about 10 grams wheat.
		53·5	61	41	24.9.18	52	2	0	
		48·5	55·5	38·5	6.1.19	156	3	2	
					3.4.19	243	0	5	
21	24A	63	80	52	13.8.18	—	4 (2 pairs)	—	Started with 10 grams wheat.
					14.10.18	62	2	2	
22	22A or 23A	63	80	52	13.8.18	—	4 (2 pairs)	—	Started with 10 grams wheat.
		53	58·5	41	14.10.18	62	0	4	
		48·5	55·5	38·5	6.1.19	146	0	4	
					3.4.19	233	0	4	
23	24A	56	70	41	24.8.18	—	4 (2 pairs)	—	Started with 10 grams wheat.
		48·5	55·5	38·5	6.1.19	135	1	1	
					3.4.19	222	0	4	
24	22A	57	70	48	24.8.18	—	4 (2 pairs)	—	Started with 10 grams wheat.
		50	58·5	38·5	7.12.18	105	0	4	
					3.4.19	222	0	4	

TABLE IV (*Calandra oryzæ*).—Increase at varying Room Temperature, in normal Wheat, from Unsorted Individuals.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
25	18A				5.2.18	—	100	—	Started with 160 grams wheat.
		54·5	67·5	46·5	18.6.18	133	18	83	
		62·8	70	59	5.10.18	242	332	90	
		53	58	48	16.12.18	314	617	104	
		47·5	54·5	38	11.4.19	430	18	736	
26	23A				5.4.18	—	100	—	Started with 130 grams wheat. On 5.10.18 all loose adults removed, and on 9.1.19 the culture yielded 338 more live and 41 more dead adults.
		52·5	60	50·5	14.5.18	39	28	72	
		60	73	53	11.6.18	67	20	80	
		64	71	60	1.7.18	87	20	80	
		68	72	64	13.8.18	130	382	80	
		64	80	52	5.10.18	183	749	104	
27	22A				10.4.18	—	100	—	Started with 500 grams wheat.
		60	73	50·5	15.7.18	96	0	98	
		68	80	63	4.9.18	147	0	99	
28	33A				31.5.18	—	20	—	Started with 10 grams wheat. On 31.7.18 all adult weevils removed and 20 more live adults from room temperature culture added. On 1.10.18, 60 live and 9 dead adults were found.
		66	73	60	9.7.18	39	9	11	
		67	71·5	64	31.7.18	61	1	19	

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* Cultures 30 and 31 were started with insects from cultures at room temperature; 26 with insects from a culture at 86–89° F. The origin of the insects in the other cultures in this Table was not recorded.

TABLE IV—*continued.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
29	36A				31.5.18	—	20	—	Started with 10 grams wheat. On 1.10.18 all fairly dry grains were cut across, and 10 live adults and no dead found.
		66	73	60	9.7.18	39	20	0	
		67	71·5	64	31.7.18	61	19	1	
		68	72	66	13.8.18	74	23	1	
		70	80	63	31.8.18	92	151	1	
		61·5	67	52	1.10.18	123	201	7	
30	23A				5.6.18	—	100	—	Started with 120 grams wheat.
		67	80	60	23.8.18	79	498	9	
		62	74	52	5.10.18	122	1,452	45	
31	24A				26.6.18	—	100	—	Started with 130 grams wheat.
		68·5	80	60	26.8.18	61	133	4	
		63	68	58	26.9.18	92	1,042	14	
32	22A				10.8.18	—	100	—	Started with about 120 grams wheat.
		64	74	52	10.10.18	61	46	52	
		54	59	48·5	9.12.18	121	1	98	
		49·5	58·5	38·5	3.4.19	236	0	99	

Discussion of Tables III and IV.

These two Tables afford conclusive evidence that *Calandra oryzæ* multiplies freely in this country at ordinary room temperatures, and under ordinary atmospheric conditions, but only during the warmer months of the year. Cultures 14–16 show that of three pairs taken in copulation on July 1st two increased largely and one not at all. Of these Culture 14 shows a 26½-fold increase between July 1st and December 12th, with a mortality of only four, but this increase probably took place in a considerably shorter time, for, owing to illness, no count was made between October 3rd and December 12th. After December 12th there was a diminution in the number of live adults. Culture 15 shows a smaller increase, but a precisely similar course of events. Cultures 17 and 18, from pairs taken in copulation on July 4th, also show an increase, though very insignificant in No. 18. On the other hand, of 10 pairs (Cultures 19–24) taken in copulation between July 31st and August 24th inclusive, only two (Cultures 19 and 20) gave any increase at all, and that quite insignificant. A pair taken in copulation on June 10th also gave no increase (Culture 13).

Cultures 25–32 (Table IV) show a precisely similar result in an even more convincing manner. No. 26 may be taken as typical. Starting with 100 adult insects on April 5th, the number fell to 20 by June 11th, remained stationary till July 1st, then increased to 382 by August 13th, and to 749 by October 5th. In Culture 27 all the hundred died before the weather became warm enough to permit of breeding. It would appear from these results that breeding begins in June or July, and continues so long as the weather remains sufficiently warm, the lower temperature limit for breeding being apparently about 65° F.

Table V (*Calandra oryzæ*).—Increase in dry Incubator, in normal Wheat, from unsorted Individuals.*

Culture No.	Wheat used.	Temperatures.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
33	22A	71	72·5	67	18.9.18	—	100	—	Started with about 100 grams wheat.
					1.1.19	105	1,445	48	

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* The origin of the insects used in this culture was not recorded.

This culture shows that *Calandra oryzæ* multiplies freely in an incubator in which no precautions are taken to keep the air moist. Comparison with Culture 12, however, at about the same temperature, seems to show that a moist atmosphere is more favourable, for in that case there was a 15-fold increase in 67 days as against the 14½-fold increase in 105 days shown in the above Table. The condition of the wheat at the end of the two experiments showed very clearly the difference in moisture of the atmosphere, for in the moist incubator it became very damp and foul, while in the dry one it remained dry and dusty. (*Cf.* the table showing changes in moisture content of wheat in incubators on p. 6.) Further information with regard to the effects of moisture is given in Section IV.

TABLE VI (*Calandra oryzæ*).—Increase under Various Conditions in Artificially Dried Wheat.*

Culture No.	Wheat used.	Temperatures.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
34	24A	82	87	77	12.8.18	—	20	—	Started with 10 grams wheat. On 12.10.18 all grains were cut across and 11 live and no dead adults and 39 larvæ found.
		(Moist	atmos	phere)	12.10.18	61	54	15	
					24.8.18	—	20	—	Started with 10 grams wheat.
35	23A	81	86	76·5	24.9.18	31	1	19	
		(Moist	atmos	phere)	3.1.19	132	1	19	
36	24A	68	76	62·5	8.8.18	—	10	—	Started with about 9 grams wheat, and 5 pairs of weevils taken in copulation.
		?	?	?	24.9.18	47	9	1	
		(Moist	atmos	phere)	6.1.19	151	117	9	
37	24A	63	80	52	12.8.18	—	20	—	Started with 10 grams wheat.
		(Roo	m cup	board)	12.10.18	61	1	18	
38	23A	53	70	38·5	24.8.18	—	20	—	Started with 10 grams wheat.
		(Roo	m cup	board)	3.4.19	222	0	20	

Cultures 34 and 36 show that in a moist atmosphere breeding can take place even in wheat that contains, at first, no moisture at all. The explanation doubtless is that the wheat gradually absorbs moisture from the atmosphere†, probably the Canadian wheat used in Culture 35, which shows no increase, more slowly than the English (compare, however, Culture 62, Table XII). Cultures 37 and 38 cannot be used as evidence in this connection as the low temperature would alone be sufficient to account for the failure to increase. (*See also* Section IV).

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* The origin of the insects used in these cultures was not recorded. The wheat was dried for 48 hours at 100° C.

† Control samples of wheat kept for the same time and under the same conditions as cultures 34 and 37 absorbed 12·4 per cent. and 7·95 per cent. of moisture respectively.

B.—*Calandra granaria.*

Table VII (*Calandra granaria*).—Increase in Incubators at various Temperatures, in moist Atmosphere, in normal Wheat, from Pairs taken in Copulation.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
39	24A		89	86	22.6.18	—	2	—	Started with 10 grams wheat; made up to 120 grams on 29.7.18.
					29.7.18	37	12	2	
					28.9.18	98	72	14	
					22.10.18	122	191	23	
40	24A		89	86	24.6.18	—	2	—	Started with 10 grams wheat; made up to 120 grams on 5.8.18.
					5.8.18	42	7	4	
					28.9.18	96	19	9	
					9.12.18	168	464	25	
41	20A	82·5	89·5	74·5	23.4.18	—	2†	—	Started with 10 grams wheat; made up to 120 grams on 10.6.18. All loose weevils removed on 18.9.18 and grain incubated again for 14 days, yielding 46 live and 3 dead adults.
					22.5.18	29	2	0	
					10.6.18	48	32	0	
					1.7.18	69	59	2	
					29.7.18	97	146	2	
					18.9.18	148	318	46	
42	23A	69	78·5	62·5	4.4.18	—	2‡	—	Started with 10 grams wheat; made up to 120 grams on 1.7.18.
					1.7.18	88	14	1	
					5.8.18	123	38	1	
					18.9.18	167	76	4	
					4.10.18	183	118	6	
43	24A	68	76	62·5	1.7.18	—	2	—	Started with 10 grams wheat; made up to 120 grams on 28.8.18.
					28.8.18	58	23	0	
					1.10.18	92	82	1	

* Cultures 39–43 (inclusive) were all started with insects taken from cultures at the incubator temperatures.

† Pair again in copulation on 25.4.18 and 16.5.18.

‡ Pair again in copulation on 16.4.18.

TABLE VIII (*Calandra granaria*).—Increase in Incubators, at various Temperatures, in moist Atmosphere, in normal Wheat, from Unsorted Individuals.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
44	23A		89	86	5.4.18	—	100	—	Started with 130 grams wheat. On 12.6.18 all loose adults removed and grain incubated again for 14 days, yielding 51 live and 8 dead adults.
					14.5.18	39	135	49	
					12.6.18	68	496	226	
45	23A		89	86	11.6.18	—	100	—	Started with 130 grams wheat.
					30.8.18	80	128	135	
46	23A	71	79	65·5	5.4.18	—	100	—	Started with 130 grams wheat. Adult weevils removed on 11.6.18 and grain again incubated till 26.6.18, yielding 300 live and no dead adults.
					14.5.18	39	98	1	
					11.6.18	67	586	4	
47	23A	70	77	66	11.6.18	—	100	—	Subculture of 46. Started with 130 grams wheat. On 30.8.18 all adult insects removed and grain further incubated till 17.9.18, yielding 367 live and 16 dead adults.
					30.8.18	80	1,098	6	

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* Cultures 44 and 47 were started with insects taken from cultures at the incubator temperatures; 46 from a culture at 86–89° F. For 45 there is no record of origin.

Discussion of Tables VII and VIII.

As in the case of *Calandra oryzæ* the cultures started from single pairs give, on the whole, much better results than those started with a large number of unsorted individuals. The most striking result is perhaps that given by Culture 40, which shows a 232-fold increase in 24 weeks at 86–89° F., but for the shorter period of 96–97 days, Culture 41, at an average temperature of 82·5° F., proved much more prolific, and it seems probable that this temperature is about the optimum for multiplication. In Table VII, however, the results are rather irregular and difficult to compare, and there are hardly enough of them to justify very definite conclusions.

Table VIII is more satisfactory in some respects, for we have here two pairs of strictly conparable companion cultures, in which the counts were made at as nearly as possible the same times. These four cultures (44–47) indicate that, as regards death rate and rate of multiplication, an average temperature of about 70°F. is more favourable than one of 86–89° F., unless, indeed, some possible difference in the amount of moisture in the atmosphere may be accountable for the result. Unfortunately we had no corresponding cultures at an intermediate temperature.

These two Tables give little information as to the winter months, but if we take into account also the results of Cultures 60, 67, 71 and 72, there can be no doubt that at suitable temperatures *Calandra granaria* continues to breed all the year round, and, indeed, we have never had any difficulty in keeping our stock going at any season.

As regards the period of development from oviposition to the emergence of the imago from the grain, Culture 39 shows that at 86–89° F. it is not more than 37 days ; Culture 41 shows that at an average temperature of 82·5° F. it is not more than 48 days, and Culture 46 shows that at an average temperature of about 71° F. it is almost certainly more than 39 days, but certainly not more than 67. These results are in sufficient agreement with Menault's average of 45 days quoted in the Introduction.

TABLE IX (*Calandra granaria*).—Increase at varying Room Temperature, in normal Wheat, from Pairs taken in Copulation.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks
		Av.	Max.	Min.					
		° F.	° F.	° F.					
48	24A	67·5	80	66·5	1.7.18	—	2	—	Started with 10 grams wheat.
		58·5	66	52	17.9.18	78	24	2	
		53·5	59	48	1.10.18	92	37	3	
		50·5	58·5	41	6.12.18	158	59	3	
		50	55·5	38·5	17.1.19	200	43	3	
					4.4.19	277	58	5	
49	24A	67·5	80	66·5	1.7.18	—	2	—	Started with 10 grams wheat.
		58·5	66	52	17.9.18	78	16	1	
		53·5	59	48	1.10.18	92	27	2	
		50·5	58·5	41	6.12.18	158	31	1	
		50	55·5	38·5	17.1.19	200	24	3	
					4.4.19	277	29	1	
50	24A	67·5	80	66·5	1.7.18	—	2	—	Started with 10 grams wheat.
		58·5	66	52	17.9.18	78	15	1	
		53·5	59	48	1.10.18	92	16	1	
		50·5	58·5	41	6.12.18	158	16	1	
		50	55·5	38·5	17.1.19	200	14	2	
					4.4.19	277	15	1	

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* All the cultures in this Table were started with insects from cultures at room temperature.

TABLE IX—*continued.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
51	23A				31.7.18	—	2	—	Started with 10 grams wheat.
		65·5	80	52	1.10.18	62	0	2	
		53	59	41	6.1.19	159	0	2	
		48·5	55·5	38·5	4.4.19	247	0	2	
52	23A				31.7.18	—	2	—	Started with 10 grams wheat.
		65·5	80	52	1.10.18	62	0	2	
		53	59	41	6.1.19	159	0	4	
		48·5	55·5	38·5	4.4.19	247	0	4	
53	22A				26.8.18	—	2	—	Started with 10 grams wheat.
		55·5	67	41	6.1.19	133	1	1	
		48·5	55·5	38·5	4.4.19	221	0	2	
54	22A				26.8.18	—	2	—	Started with 10 grams wheat.
		55·5	67	41	6.1.19	133	0	2	
		48·5	55·5	38·5	4.4.19	221	0	2	

TABLE X (*Calandra granaria*).—Increase at varying Room Temperature, in Normal Wheat, from Unsorted Individuals.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F'	° F.					
55	23A				5.4.18	—	100	—	Started with 130 grams wheat.
		52·5	60	50·5	14.5.18	39	99	1	
		66	73	53	11.6.18	67	96	4	
		64	71	60	1.7.18	87	93	7	
		68	72	64	13.8.18	130	93	7	
		64	80	52	5.10.18	183	75	25	
		52·5	59	41	2.1.19	272	66	80	
		49·5	55·5	38·5	4.4.19	364	28	133	
56	22A				10.4.18	—	100	—	Started with 500 grams wheat.
		60	73	50·5	15.7.18	96	80	17	
		68	80	63	3.9.18	146	2,203	61	
57	23A				3.6.18	—	100	—	Started with 120 grams wheat.
		67	80	60	23.8.18	81	282	32	
		62	74	52	3.10.18	122	842	104	
58	24A				26.6.18	—	100	—	Started with 120 grams wheat.
		68·5	80	60	26.8.18	61	150	0	
		63	68	58	26.9.18	92	670	5	
59	22A				10.8.18	—	100	—	Started with 120 grams wheat.
		64	74	52	10.10.18	61	88	10	
		54	59	48·5	9.12.18	121	119	12	
		49·5	58·5	38·5	4.4.19	237	97	93	

* Culture 55 was started with insects from a culture at 86–89° F.; 58 with insects from a culture at room temperature. The origin of the insects in the other cultures in this Table was not recorded.

Discussion of Tables IX and X.

The cultures afford no evidence that breeding begins before July, but pairs were found in copulation on the first of that month, at room temperature. Culture 56, started with 100 weevils on April 10th, showed a diminution to 80 on July 15th, but by September 3rd these had increased to 2,203. Of three pairs taken in copulation on July 1st all showed a considerable increase. Cultures 48–50 all show that no increase takes place after December 6th, and probably it ceases earlier. In this connection it is very significant that two pairs taken in copulation on July 31st, and two pairs taken in copulation on August 26th gave no increase at all by January 1st (Cultures 51–54). Culture 59, however, started with 100 weevils on August 10th, gave a slight increase by December 9th. The result of Culture 55 is very difficult to explain. In this case 100 weevils in 130 grams of wheat had diminished to 75 live adults by October 5th, with only 25 dead, but by April 4th, the number of dead had increased to 133, while the living had fallen to 28. July and August appear to be the months in which breeding chiefly takes place, the minimum temperature being probably about 65° F. The highest rates of increase were about 30-fold in 158 days (probably less) from a pair in copulation (Culture 48), and 22-fold in 146 days from 100 unsorted individuals (Culture 56).

TABLE XI (*Calandra granaria*).—Increase in Dry Incubator, in Normal Wheat, from Unsorted Individuals.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
60	22A				18.9.18	—	100	—	Started with about 100 grams wheat.
		71	72·5	67	1.1.19	105	170	22	
		70	71·5	64	28.3.19	191	264	225	

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* The origin of the insects used in this culture was not recorded.

This culture seems to show that *Calandra granaria* increases very slowly in a dry atmosphere and that there is a very heavy mortality. It should be compared with Culture 47, at about the same temperature, but in a moist atmosphere, where 100 increased to 1,098 in 80 days, with a very low mortality, though the grain became damp and very foul. In Culture 60 the grain remained dry and dusty. Comparison should also be made with Table V, which shows that *Calandra oryzæ* increases much more rapidly under these conditions (*see also* Section IV).

TABLE XII (*Calandra granaria*).—Increase under various Conditions in Artificially dried Wheat.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
61	24A	82	87	77	12.8.18	—	20	—	Started with 10 grams wheat. On 12.10.18 all grains cut across and 6 live adults and 7 dead (?) found, and 19 larvæ.
		(Moist	atmos	phere)	12.10.18	61	49	19	
					24.8.18	—	20	—	Started with 10 grams wheat. On 31.12.18 cover of jar was found pierced, and probably many weevils had escaped.
62	23A	81	86	76·5	24.9.18	31	5	15	
		(Moist	atmos	phere)	3.1.19.	132	4	41	
63	24A	68	76·5	62·5	12.8.18	—	20	—	Started with 10 grams wheat.
		(Moist	atmos	phere)	12.10.18	61	5	15	
64	24A	63	80	52	12.8.18	—	20	—	Started with 10 grams wheat.
		(Roo	m cup	board)	12.10.18	61	3	17	
65	23A	53	70	38·5	24.8.18	—	20	—	Started with 10 grams wheat.
		(Roo	m cup	board)	4.4.19	223	0	20	

Culture 61 shows that in a moist atmosphere breeding can take place even in wheat that contains, at first, no moisture at all, doubtless because, as already indicated under Table VI, the wheat gradually absorbs moisture from the atmosphere.† Cultures 64 and 65 cannot be used as evidence in this connection as the low temperature would alone be sufficient to account for the failure to increase (*see also* Section IV).

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* The origin of the insects used in these cultures was not recorded. The wheat was dried for 48 hours at 100° C.

† Control samples of wheat kept for the same time and under the same conditions as Cultures 61, 63 and 64 absorbed 12·4 per cent., 11·65 per cent., and 7·95 per cent. of moisture respectively.

C.—*Comparative Fertility of Calandra oryzæ and C. granaria.*

A careful examination of the foregoing Tables shows very clearly that at all temperatures and under all conditions, so far as the investigations go, when breeding takes place at all *Calandra oryzæ* increases much more rapidly than *C. granaria.* This fact is most clearly brought out by a series of companion cultures run concurrently (or very nearly so), and under exactly the same conditions. This series may be briefly epitomised as follows :—

At 86–89° F. in moist Atmosphere.

Culture 2 (*C. oryzæ*).—1 pair gave 470 live and 101 dead adults in 122 days.
Culture 39 (*C. granaria*).—1 pair gave 191 live and 23 dead adults in 122 days.

Culture 8 (*C. oryzæ*).—100 (unsorted) gave 1,160 live and 65 dead adults in 39 days.
Culture 44 (*C. granaria*).—100 (unsorted) gave 135 live and 49 dead adults in 39 days.

At an Average Temperature of 82·5° F. in moist atmosphere.

Culture 4 (*C. oryzæ*).—1 pair gave 758 live and 32 dead adults in 97 days.
Culture 41 (*C. granaria*).—1 pair gave 146 live and 2 dead adults in 97 days.

At an average Temperature of about 71° F. in moist Atmosphere.

Culture 12 (*C. oryzæ*).—100 (unsorted) gave 1,502 live and 26 dead adults in 67 days.
Culture 46 (*C. granaria*).—100 (unsorted) gave 586 live and 4 dead adults in 67 days.

At Varying Room Temperature.

Culture 14 (*C. oryzæ*).—1 pair gave 53 live and 4 dead adults in 159 days.
Culture 49 (*C. granaria*).—1 pair gave 31 live and 1 dead adult in 158 days.

Culture 15 (*C. oryzæ*).—1 pair gave 20 live and 3 dead adults in 159 days.
Culture 48 (*C. granaria*).—1 pair gave 59 live and 3 dead adults in 158 days.

Culture 30 (*C. oryzæ*).—100 (unsorted) gave 1,452 live and 45 dead adults in 122 days.

Culture 57 (*C. granaria*).—100 (unsorted) gave 842 live and 104 dead adults in 122 days.

Culture 31 (*C. oryzæ*).—100 (unsorted) gave 1,042 live and 14 dead adults in 92 days.

Culture 58 (*C. granaria*).—100 (unsorted) gave 670 live and 5 dead adults in 92 days.

In dry Atmosphere at about 71° F.

Culture 33 (*C. oryzæ*).—100 gave 1,445 live and 48 dead adults in 105 days.

Culture 60 (*C. granaria*).—100 gave 170 live and 22 dead adults in 105 days.

The only anomaly in these results is in the pair of Cultures 15 and 48, where *C. granaria* gave a higher rate than *C. oryzæ*, but this may safely be regarded as a mere accident and is to some extent counterbalanced by the corresponding pair 14 and 49, run concurrently and showing the usual predominance of *C. oryzæ*.

The following Table (XIII), showing the produce of mixed cultures of the two species brings out exactly the same result. Culture 70, at room temperature, appears at first sight to be anomalous, but this is not really the case, for, owing to the low temperature during the earlier part of the experiment, the number of live adult *oryzæ* fell to 8, while that of adult *granaria* only fell to 34, so that there were about four times as many *granaria* left to breed, and the final result was only such as might have been anticipated. The figures given in this table suggest very strongly that whenever the two species come into direct competition with one another *Calandra granaria* will tend to be eliminated.

Culture 66 was, for some unknown reason, a complete failure and cannot be taken into account. It seems desirable to record it, if only to show that such failures sometimes occur.

Table XIII (*Calandra oryzæ* and *C. granaria* mixed).—Increase under various Conditions in Normal Wheat.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.		Dead Adults.		Remarks.
		Av.	Max.	Min.			Oryzæ.	Gran-aria.	Oryzæ.	Gran-aria.	
		° F.	° F.	° F.							
66	23A	(Moist	89 atmos	86 phere)	31.7.18 2.1.19	— 155	2 1	2 0	— 3	— 6	Started with about 10 grams wheat, and one pair of each species in copulation.
67	14A	(Moist	89 atmos	86 phere)	12.12.17 19.3.18 26.3.18	— — 104	100 3,128	100 217	— 257 (plus remov 11.	— 96 those ed on 1.18)	On 11.1.18 205 live adults and 84 dead were found. These were not sorted into species, and the live only were put back. At the March examination all adults were removed and sorted and the grain again incubated till 4.4.18, yielding 285 more live adult *oryzæ*, 37 dead *oryzæ*, 4 live *granaria*, and 11 dead *granaria*.
68	23A	(Moist	89 atmos	86 phere)	5.4.18 17.7.18	— 103	50 970	50 13	— 659	— 157	Started with 130 grams wheat. On 17.7.18 all loose adults removed and grain incubated again till 3.8.18, yielding 90 more live *oryzæ*, 40 dead *oryzæ*, no live *granaria*, and 1 dead *granaria*.

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* Cultures 66, 68, 71 and 72 were started with insects from cultures at the same temperature; 69 and 70 with insects from cultures at 86–89° F. The origin of the insects in 67 was not recorded.

TABLE XIII—*continued.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.		Dead Adults.		Remarks.
		Av.	Max.	Min.			Oryzæ.	Granaria.	Oryzæ.	Granaria.	
		° F.	° F.	° F.							
69	23A	70·5	79	65·5	5.4.18	—	50	50	—	—	Started with 130 grams wheat. On 18.7.18 all loose adults removed and grain incubated again till 3.8.18, yielding 373 more live *oryzæ*, 56 dead *oryzæ*, 22 live *granaria* and 5 dead *granaria*.
		(Moist	atmos	phere)	18.7.18	104	1,404	304	9	28	
70	23A	58·5	73	50·5	5.4.18	—	50	50	—	—	Started with 130 grams wheat. On 5.9.18 all loose adults removed. On 20.9.18 found 36 more live *oryzæ* and 133 more live *granaria*.*
		68·5	80	63	18.7.18	104	8	34	41	17	
		(Roo	m cup	board)	5.9.18	153	292	551	47	71	
71	24A	72	77	70	5.8.18	—	4	4	—	—	Started with about 100 grams wheat, and two pairs of each species in copulation.
		70·5	72·5	69	7.10.18	63	31	2	1	4	
		(Dry	atmos	phere)	16.1.19	164	322	52	5	19	
72	23A	72	77	70	5.8.18	—	4	4	—	—	Started with about 100 grams wheat, and two pairs of each species in copulation.
		70·5	72·5	69	7.10.18	63	38	2	2	2	
		(Dry	atmos	phere)	16.1.19	164	506	9	11	5	

* It will be observed that on 18.7.18, 49 *oryzæ* and 51 *granaria* were recorded instead of 50 of each. This was probably due to a wrong identification of one weevil, a mistake easily made when it is desirable to handle the insects as little as possible. In other cases, when the experiment was ended, it was possible to kill the insects and examine them more carefully.

D.—*Rhizopertha dominica.*

Table XIV (*Rhizopertha dominica*).—Increase under various Conditions.

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
		° F.	° F.	° F.					
73	20A	(Moist	89 atmos	86 phere)	16.4.18 29.7.18	— 104	100 315	— 103	Started with 65 grams wheat. On 29.7.18 all loose adults removed. Grain again incubated till 12.8.18, when 69 live adults and no dead were removed; again incubated till 19.8.18, when 111 live and 9 dead adults were found.
74	22A	(Moist	89 atmos	86 phere)	12.8.18 29.10.18	— 78	100 532	— About 400	Started with 120 grams wheat.
75	24A*	82 (Moist	87 atmos	77 phere)	12.8.18 12.10.18	— 61	20 33	— 3	Started with 10 grams wheat. On 12.10.18 all grains cut across, yielding 12 more live and 39 dead (?) adults.
76	23A*	81 (Moist	86 atmos	76·5 phere)	24.8.18 24.9.18 23.1.19	— 31 132	20 14 103 +	— 2 20	Started with 10 grams wheat. On 31.12.18 cover was found pierced and many insects had escaped.

* Dried at 100° C. for 48 hours.

Note.—The apparent diminution in the total number of insects, live and dead, shown in Cultures 78, 79, 80, 82, 83, 84, is to be accounted for by their habit of concealing themselves in the grains, for which greater allowance must be made than in the case of the weevils (*see* remarks on Culture 75).

TABLE XIV—*continued.*

Culture No.	Wheat used.	Temperature.			Dates.	Days.	Live Adults.	Dead Adults.	Remarks.
		Av.	Max.	Min.					
77	20A	° F. 72·5 (Moist	° F. 79 atmos	° F. 65·5 phere)	16.4.18 30.7.18	— 105	100 163	— 3	Started with 65 grams wheat. On 30.7.18 all loose adults removed. Grain again incubated till 12.8.18, when 114 live and two dead adults were removed; again incubated till 19.8.18, yielding 77 live and one dead adult.
78	24A*	68 (Moist	76·5 atmos	62·5 phere)	12.8.18 12.10.18	— 61	20 4	— 7	Started with 10 grams wheat.
79	22A	68·5 (Moist	76·5 atmos	62·5 phere)	12.8.18 30.10.18	— 79	100 82	— 4	Started with 110 grams wheat.
80	24A	72 (Dry	77 atmos	70 phere)	7.8.18 7.11.18	— 92	50 39	— 6	Started with about 50 grams wheat.
81	20A	58 (Roo	73 m cup	48 board)	16.4.18 30.7.18	— 105	100 79	— 14	Started with 65 grams wheat. On 30.7.18 all loose adults removed. On 12.8.18 two more live adults removed. On 14.1.19 seven dead and no live found.
82	24A	66·5 (Roo	80 m cup	52 board)	30.7.18 30.10.18	— 92	50 44	— 5	Started with about 90 grams wheat.
83	23A	66·5 (Roo	80 m cup	52 board)	30.7.18 30.10.18	— 92	50 42	— 5	Started with about 90 grams wheat.
84	24A*	63 (Roo	80 m cup	52 board)	12.8.18 12.10.18	— 61	20 6	— 8	Started with 10 grams wheat.

* Dried at 100° C. for 48 hours.

The foregoing Table shows that at a temperature of 86–89° F., in a moist atmosphere, *Rhizopertha dominica* multiplies extensively, the maximum apparent increase obtained being 532 live and about 400 dead adults in 78 days from 100 unsorted individuals (Culture 74). Cultures 75 and 76 also show a very considerable increase at an average temperature of 82° F. in a moist atmosphere. Culture 77 again shows a considerable increase at an average temperature of 72·5° F. (moist), but two others (78, 79) show no apparent increase under these conditions, nor was there any apparent increase in a dry atmosphere at about 72° F. (Culture 80). Culture 81, at room temperature (starting with 100) showed no apparent increase in 105 days, but in the final result a surplus of two appeared, possibly indicating a miscount in the original number, very probable where dealing with a small, active insect like Rhizopertha, which cannot be handled much without fear of injury. On the whole we are led to conclude that it is highly improbable that Rhizopertha could ever become a serious pest in this country, the lower temperature limit for breeding being probably about 70° F. (*see also* Section IV).

III. TEMPERATURE LIMITS FOR THE LIFE OF THE INSECTS.

We have already pointed out, as a result of the analysis of the statistical Tables, that for both species of grain-weevil a temperature of about 82·5° F. is probably near the optimum for multiplication. In both species, also, multiplication ceases at ordinary room temperatures during the winter months, the lower limit for breeding being probably about 65° F. For *Rhizopertha dominica* both the optimum and minimum appear to be somewhat higher, the best results having been obtained at 86–89° F., while the lower limit is probably about 70° F.

As regards the effect of extreme temperature conditions upon the life of the adult insects we have some very interesting observations to record, showing well-marked physiological differences between the species. Our observations concern more especially the two species of weevil and we will deal with them first.

When cultures of *Calandra oryzæ* and *C. granaria*, which have been kept at ordinary room temperature over the winter, are examined at the beginning of spring, it is found that in the case of the former the adult insects are usually all dead, while in the case of the latter a very large proportion of them are alive and vigorous. Thus a heavily infected culture of each species in a large bottle of wheat (holding about 900 grams) was put away in a dark cupboard in the laboratory on October 17th, 1918, and taken out and examined on April 8th, 1919. In the bottle containing *C. oryzæ* 603 dead adults were found loose among the grains and no live ones, but live advanced larvæ were found on cutting open some of the grains three weeks later. In that containing *C. granaria* 503 live adults and 57 dead were found. Two live advanced larvæ were also sifted out with the dust, and no doubt many more remained in the grains, two being actually found on cutting open a comparatively small number of the latter.

Precisely similar results are shown in some of the cultures at room temperature recorded in Tables III and IV, and IX and X. In Cultures 14, 15, 17, 18, 20 and 32 (*C. oryzæ*) all adult insects died during the winter months. In Cultures 48, 49, 50 and 55 (*C. granaria*), on the other hand, the mortality during the winter months appears to have been no higher than at any other time of the year. During the winter the temperature in the laboratory never fell below 38° F.

In order to try the effect of a lower temperature, cultures were also kept in a very exposed gallery immediately beneath the roof, where there was never any artificial heat and where the temperature on February 12th–13th fell to 27° F., and was at or below freezing point on nine nights, the average temperature for the whole period (70 days) being 42° F. Companion cultures were kept in the laboratory at ordinary room temperature (58° to 38·5° F., average 49·5° F.). All the cultures were put up on January 28th, 1919.

Culture A consisted of about 150 grams of Canadian wheat taken from a stock heavily infected with *Calandra granaria*, which had been kept at room temperature since August, 1918. This was kept in the laboratory and on being sifted on April 8th yielded 164 live insects and 1,054 dead.

Culture B, resembling A in all respects, being half of the same sample, well mixed, was kept in the gallery and on April 8th yielded 85 live insects and 1,153 dead.

Culture C consisted of about 300 grams of Indian wheat from a stock heavily infected with *Calandra oryzæ*, which had been standing in the laboratory since October, 1917. This was kept in the laboratory, and on April 8th yielded no live insects and 1,340 dead.

Culture D, resembling C in all respects, being half of the same sample, well mixed, was kept in the gallery, and on April 8th yielded no live insects and 1,303 dead.

In all these cultures live insects were observed at the beginning of the experiment. At the close of the experiment the sifted grain (all loose weevils having been removed) was incubated at 77–79° F. for 42 days, with the following results:—

Culture A (*Calandra granaria*) yielded 5 live and 3 dead adults.
Culture B (*Calandra granaria*) yielded 2 live and 2 dead adults.
Culture C (*Calandra oryzæ*) yielded 308 live and 7 dead adults.
Culture D (*Calandra oryzæ*) yielded 0 live and 1 dead adult.

These experiments show clearly that while *Calandra granaria* passes the winter in this country chiefly in the adult condition, very few larvæ being present in this case, *C. oryzæ* does so chiefly— in this case entirely —in the larval condition, for no adults were seen in Culture C until 16 days after the commencement of incubation, whereas, had pupæ been present, they would have emerged much sooner. They also show that the low temperature of the exposed gallery was fatal to the larvæ of *C. oryzæ* (*vide* Culture D). The result as to the larvæ of *C. granaria* (Culture B) is not so conclusive, for though four adults appeared on incubation, it is conceivable that all of these may have been concealed as adults in grains. This, however, is not very likely, for no adult was seen until 34 days after the commencement of incubation.

More exact experiments were made by subjecting the insects to a constant temperature of about 33° F. Thermos flasks containing ice were used for this purpose, the insects being enclosed in little cambric bags in a test-tube plunged in the ice. A thermometer was placed in the test tube and the mouths of the tube and of the thermos flask were plugged with cotton wool. The first experiment lasted from March 19th to March 26th and during the whole time the temperature remained at 33° F. When first taken from the ice the insects (100 each of *Calandra oryzæ, C. granaria* and *Rhizopertha dominica**) were all motionless and apparently dead. On incubation at 86–89° F., however, a certain number of them revived, as shown below.

Number of Insects showing Signs of Life.

	C. granaria.	*C. oryzæ.*	*Rhizopertha dominica.*
March 26th, 11.15 a.m.	Several	0	0
,, 26th, 12 noon	Nearly all	4	3
,, 27th, 10.30 a.m.	100	48	47
,, 28th	95	32	47
,, 31st	95	1	32

It was thought desirable to repeat the experiment with a longer period of exposure. It was, therefore, started again on March 27th, 1919. The temperature kept at 33° F. till April 4th, when it rose to 34° F. Fresh ice was then added, and the temperature fell again to 33° F. By April 7th it had risen to 36° F., and the insects (100 of each species) were removed at 2.5 p.m. In less than five minutes some of the *C. granaria* had begun to recover, and on incubation at 77–79° F. other recoveries took place as shown below.

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* All the insects were taken from Cultures at 70° F.

Number of Insects showing Signs of Life.

	C. granaria.	*C. oryzæ.*	*Rhizopertha dominica.**
April 7th, 3 p.m.	Most	0	0
„ 7th, 5 p.m.	—	0	0
„ 8th, 10.15 a.m.	92	3 (Very feeble)	0
„ 9th, 10.15 a.m.	91	3 (Very feeble)	0

It is obvious from these results that neither *Calandra oryzæ* nor *Rhizopertha dominica*† can withstand exposure to a temperature of 33° F. for more than a very few days, while *C. granaria* is much hardier. All these species become torpid and motionless at low temperatures. *C. granaria* recovers much more quickly from this condition than *C. oryzæ*, so that it is possible to sort out the two species by subjecting them to a temperature of about 34° F. and picking out those which recover first. This was done with a mixed lot of 50 *C. oryzæ* and 50 *C. granaria,* exposed to a temperature of 34° F. for 42 hours. At the end of this time all the weevils were apparently dead, but in about half-an-hour 50 had recovered, and all these proved to be *C. granaria.* It was two hours more before any of the *C. oryzæ* showed signs of recovery, and ultimately only 34 out of the 50 survived.

As to the question of hibernation, it is clear from our experience that *C. granaria* can pass the English winter in the adult condition, becoming torpid as the temperature falls. The fact that advanced larvæ of this species were found in a room temperature culture on April 8th makes it practically certain that it also passes the winter in the larval state. *Calandra oryzæ,* as we have already pointed out, differs from *C. granaria* in its greater susceptibility to low temperatures, at any rate in the adult condition. That it can sometimes survive the winter at ordinary room temperatures in this country is evident from the fact that we have found recrudescence of weevilling taking place in a large stock sample of Indian wheat containing *Calandra oryzæ* after standing in the laboratory all through the winter, but the history of Culture 25 is most conclusive on this point. This is altogether one of the most instructive of the entire series, for it was continued for 14 months at room temperature, and shows very clearly the rise and fall in the number of weevils according to season (*see* Table IV). On December 16th, 1918, it was found to contain 617 live loose adults, and 104 dead. By April 11th the number of live adults had fallen to 18 while that of dead had risen to 736, showing the usual mortality during the winter months, but with a small percentage of survivals. After sifting the grain, moreover, on April 11th, no less than seven live advanced larvæ were found loose amongst the dust, and on cutting open a number of the grains a very large proportion of them (probably half) were found to contain advanced larvæ in a living condition, which emerged in large numbers as perfect insects on being incubated (*see* p. 45). In the original culture (25), kept at room temperature, they began to emerge from the grains about the middle of June (1919).

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* The Rhizopertha in this case were taken from a culture at 87–89° F., the others as before.

† In the adult state.

Evidently *Calandra oryzæ* at ordinary room temperature in this country passes the winter months chiefly in the larval state inside the grains. The actual temperature of the room in which this culture was kept ranged from 54·5° F. to 38° F. between December 16th and April 11th (in the day time).

Similar results were obtained from Cultures 14, 15, 20 and 32 (*Calandra oryzæ*), No. 32 being by far the most convincing. It will be seen, by reference to Table IV, that out of 100 adults placed in the wheat on August 10th, 1918, 99 were found dead, and none alive, on April 3rd of the following year, the culture having been kept at room temperature throughout the winter. The 99 adult insects were all removed, and the apparently clean grain was incubated at about 86–89° F., yielding 18 live and 5 dead insects in 20 days.

It is hardly necessary to point out that the differences between the three species investigated in respect of their susceptibility to low temperature are correlated with their natural geographical distribution, *Calandra granaria* being generally believed to be characteristic of more northern latitudes than either of the other two.

As to the upper temperature limit for the life of the adult insects we have little to add to what is already known. Professor Maxwell Lefroy, according to the "Times" report of a lecture recently delivered at the Royal Institution, speaking of the destruction of grain insects by heating, stated that a temperature of 145° F., applied for three minutes, killed anything. Our own experiments go a long way to support this contention as regards *Calandra oryzæ*, *Calandra granaria* and *Rhizopertha dominica*.

It is interesting to observe, however, that the lethal point is not the same for all three species, but that these exhibit certain differences in susceptibility to high temperatures. In our first experiment 50 of each species were enclosed in cages made from short lengths of glass tubing covered at the ends with cambric. The cages were placed in a test tube containing a thermometer and the test tube was plunged in water heated to about 131° F. The temperature in the test tube rose fairly rapidly. The effect upon the insects was as follows:—

Calandra oryzæ.—Between 86° and 122° F. the insects were very active indeed. At about 124° all movement ceased. The temperature was allowed to rise to 127·5°, when the insects were removed in their cage, cooled to room temperature and then incubated at about 77° F. in a moist atmosphere. Ten of them had revived on the following day, but all the rest were found to have been killed.

Calandra granaria.—Between 86° and 122° F. the insects were very active indeed, and movement did not cease till about 127·5°. Removed and incubated under the same conditions as *C. oryzæ* there were 13 recoveries by the following day, and 9 more by the day after.

Rhizopertha dominica.—The insects became motionless at about 125·5° F. Removed and incubated under the same conditions as the preceding there were 47 revivals by the following day.

In our second experiment 100 of each species, taken from cultures at 86–89° F., were enclosed in small copper gauze cages, and these were places in a water oven, heated to 131° F., where they were allowed to remain for three minutes. The temperature at first dropped to 129° F. but rose again to 131°. After three minutes exposure the insects were removed and incubated as before and on the following day 97 of the Rhizopertha had revived, but the Calandras of both species were all dead.

It is obvious from these two experiments that Rhizopertha can withstand a higher temperature (for three minutes) than either of the two weevils, while from the first experiment it seems possible that *Calandra oryzæ* may be a little more susceptible than *C. granaria.*

It remained to experiment at a lower temperature with the weevils and at a higher one with Rhizopertha. Accordingly, the second experiment was repeated with the two Calandras at a temperature of 120–122° F. for three minutes. The weevils became motionless as before, but all revived within an hour. It was also repeated with Rhizopertha at a temperature of 143·5–145·5° for three minutes, resulting in the death of all the insects except six, which, though still motionless on the following morning (Saturday) were found to have recovered by Monday.

It follows, therefore, that for an exposure of three minutes the lethal temperature for the two weevils in the adult state lies between 120° and 131° F., and for Rhizopertha at about 146° F.

With a view to determining the effect of heating upon the immature stages of *Calandra oryzæ* the following experiment was performed with a portion of Culture 25, from which all visible adult weevils had been removed. It was known that on April 11th, 1919, this culture contained a large number of live advanced larvæ in the grains (*see* p. 43). On the same date two lots of the infected grain, each weighing 20 grams, were weighed out, the grain having been previously well mixed. One of these lots was placed in a test-tube with a thermometer inserted in the middle of the grain. The test-tube was then plunged in a beaker of hot water. The temperature, when first read, was 86° F. In about five minutes it rose to 145·5° F., when the test-tube was removed from the hot water, and its contents spread out to cool, before being placed in a cambric-covered jar for incubation. The second lot of

20 grams was used as a control and, of course, not heated. Both were then incubated at 77–79° F., and examined almost daily. On April 26th, one live adult was seen in the control. On the 28th the contents of both jars were turned out and examined, 21 live adults being found in the control and none in the other. On May 10th another examination was made, 226 live adults and 2 dead being found in the control, and no signs of life in the other. It seems quite clear from this experiment that heating for five minutes to a temperature of 145·5° F. is quite sufficient to kill the larvæ as well as the adults of *Calandra oryzæ.* In order to make sure that the heated grain had been completely sterilised it was again incubated till May 23rd, making a total of 42 days, but with no result. Dead larvæ were found in some of the grains on cutting them open.

Unfortunately we could not spare the time to extend these observations to other species, but there can be no reasonable doubt of the efficacy of heating the grain to about 145° F. as a means of sterilising it as regards insect pests.

IV. CONDITIONS NECESSARY AS REGARDS MOISTURE.

It has long been known that the presence of a certain amount of moisture is necessary for the continued existence and multiplication of weevils and the necessity of getting the wheat as dry as possible when it is intended to store it for long periods is fully recognised. The experiments hitherto made with a view to determining the degree of moisture required by the weevils are, however, so far as they are known to us, quite unreliable, for such experiments have been conducted in closed bottles and no allowance has been made for the fact that hermetical sealing alone is fatal to insect life, irrespective of any other factor.

Sufficient attention, also, has not been paid to the hygroscopic character of wheat, which renders it necessary not only that the wheat should be thoroughly dried in the first instance, but also that it should be stored in such a way as to prevent the access of moisture and the consequent renewed liability to weevilling. This is rightly insisted upon by Mr. A. Howard, Imperial Economic Botanist to the Indian Government, in a letter addressed to the Chairman of the Grain Pests Committee on April 4th, 1918, from which we quote the following :— "Sun-dried wheat, if stored in a dry building, will keep for years and weevils will not attack it. If, however, moist air is allowed to circulate over the sacks of wheat, water is absorbed and the grains become soft enough for the weevils to attack them. This is prevented in India by filling the storehouse as completely as possible with sacks of wheat and taking up any space left with dry chaffed straw packed tightly into all the vacant places. If the walls and floor are not well made, a space 2 ft. wide all round the sacks is filled with tightly packed dry chaff or chaffed straw. When attention is paid to these points in

India, no damage by weevils or grain moths need be feared. If similar methods are adopted elsewhere, the surplus of countries like Canada and Australia could, I think, be stored for several years with complete safety, and shipped to England as tonnage becomes available. One important point is not referred to in the Australian reports, namely, the fact that hard wheats, like sample of Pusa 4 enclosed, are not attacked by weevils even after long exposure to damp air. If packets of soft and of hard wheats are left exposed to the air in a room at Pusa during the monsoon, the soft wheats are always reduced to powder by weevils in a very short time while hard wheats remain unaffected even after lying about for six months or so. Hence in countries where hard and soft wheats are grown, the soft wheat should be shipped at once and the hard wheats should be stored."

It should be noted in connection with the above that the conditions of storage described are such as to result in a very complete exclusion of air—indeed the exclusion of air is necessary in order to secure the exclusion of moisture, and the beneficial results may perhaps be attributed as much to the absence of oxygen and the accumulation of carbon dioxide as to the dryness of the wheat. At any rate the evidence is all in favour of air-tight storage.

We have made experiments with the sample of Pusa 4 wheat supplied by Mr. Howard, which do not support his contention that this wheat is not attacked by weevils even after long exposure to damp air. This sample, when examined on June 19th, 1918, was found to contain 10·6 per cent. of water. Culture 9 (Table II) shows that in a moist incubator at 86–89° F., *Calandra oryzæ* not only lived but multiplied in this wheat, the live adults increasing from 20 to 98 in 123 days. Culture 28 (Table IV), at room temperature, shows a similar but less pronounced result.

It is obvious that, in dealing with the effects of dryness, two possible sources of moisture have to be considered :—(1) The initial moisture of the wheat, and (2) the moisture of the atmosphere in which the wheat is stored. Certain of the experiments recorded in the foregoing Tables afford some information as to these points. Cultures 33 (Table V), 60 (Table XI) and 72 (Table XIII) show that in wheat with an initial moisture content of about 10 per cent.* both *Calandra oryzæ* and *C. granaria* live and multiply even in a dry atmosphere. Culture 71 (Table XIII) shows the same thing for both species in wheat with an initial moisture content of 15·6 per cent. Cultures 34–38 (Table VI), in dried wheat containing no initial moisture, show that in moist incubators *Calandra oryzæ* may give a considerable increase, but we get no increase in the ordinary atmosphere and at the ordinary temperature of the laboratory. Cultures 61–65 (Table XII) show similar results for *Calandra granaria*. In all these cases, where multiplication took place, moisture was available either from the wheat or from the atmosphere.

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* Estimated from the information given in the Table on p. 5.

In order to test the matter more accurately and to eliminate the fatal error arising from the use of stoppered bottles to keep out moisture, we decided to experiment with artificially dried wheat in a dry incubator. Both species of weevil and also *Rhizopertha dominica* were tested in this way as to their powers of drought-resistance. Two sets of experiments were carried out, (*a*) with wheat (23A) dried to 9·7 per cent. of moisture, and (*b*) with the same wheat dried to 6·1 per cent. In both cases No. 3 incubator was used, at a temperature of 68–73° F., and the dryness of the atmosphere was demonstrated by the fact that control samples of wheat continued to lose moisture therein, the moisture content falling in the first case from 9·7 per cent. to 8·2 per cent., and in the second from 6·1 per cent. to 5·35 per cent. during the experiment. The results of these experiments are shown in the following Table.

TABLE XV.—Cultures of Calandra and Rhizopertha in partially dried Wheat and in a Dry Incubator at 68–73° F.

Culture No.	Species.	Dates.	Days.	Moisture Content of Control Wheat.*	Live Adults.	Dead Adults.	Remarks.
85	*Calandra oryzæ*	26.3.19	—	9·7	100	—	Culture started with about 110 grams wheat. Dead weevils removed on 20.5.19, and wheat re-incubated as before till 13.6.19, but without result.
		20.5.19	55	8·5	0	100	
		13.6.19	79	8·2	0	0	
86	*Calandra granaria*	26.3.19	—	9·7	100	—	Culture started with about 110 grams wheat. Only the 28 live weevils were replaced on 20.5.19 for further incubation.
		20.5.19	55	8·5	28	72	
		13.6.19	79	8·2	18	11	
87	*Rhizopertha dominica*	26.3.19	—	9·7	100	—	Culture started with about 110 grams wheat. All insects, live and dead, replaced on 21.5.19 for further incubation.
		21.5.19	56	8·5	87	9	
		13.6.19	79	8·2	80	13	
88	*Calandra oryzæ*	19.4.19	—	6·1	100	—	Culture started with about 100 grams wheat.
		13.6.19	55	5·35	0	99	
89	*Calandra granaria*	19.4.19	—	6·1	100	—	Culture started with about 100 grams wheat.
		13.6.19	55	5·35	1	100	
90	*Rhizopertha dominica*	19.4.19	—	6·1	100	—	Culture started with about 100 grams wheat.
		13.6.19	55	5·35	39	60	

NOTE.—The specimens of *Calandra oryzæ* and *C. granaria* used in these cultures were taken from previous cultures at about 70° F.; those of Rhizopertha were taken from a culture at about 86° F.

* The moisture content of the wheat in the culture at the commencement of the experiment was the same as that of the control. The actual dates of determination of the later moisture contents of the control were 21/5/19 and 17/6/19.

Cultures 85 and 86 in the above Table indicate that in wheat with an initial moisture content of 9·7 per cent., falling to 8·5 per cent. in 55 days and to 8·2 per cent. in 79 days, and at a temperature of 68–73° F., neither *Calandra oryzæ* nor *C. granaria* is able to multiply, the *Calandra oryzæ* being all apparently killed off in 55 days, and the *C. granaria* diminishing in numbers from 100 to 18 in 79 days. That there had been time for breeding to take place, had the conditions as regards moisture been more favourable, is clearly indicated by comparison of Cultures 6, 43, 71 and 72, at approximately the same temperature. Cultures 88 and 89, with wheat of only 6·1 per cent. initial moisture, show a similar result, but more pronounced in the case of *C. granaria.* The existence of one live adult at the close of the experiment in Culture 89 is difficult to account for, especially as there were 100 dead. It is possible that one egg had developed or that a miscount had been made in the original number. In any case, the occurrence of one survivor is a matter of small importance. We conclude, from the results of these cultures, that wheat with a moisture content of about 8 per cent., *stored in a sufficiently dry atmosphere,* is safe from the attacks of weevils, a conclusion which harmonises very well with current opinions on the subject. In all the cultures the grain at the conclusion of the experiment was practically untouched, there being very few signs of feeding.

Cultures 87 and 90, under exactly the same conditions, show that *Rhizopertha dominica* (in the adult condition) resists drought better than either of the two Calandras. There was, however, a very heavy mortality even with this species in the drier wheat, and, although the temperature of our cultures was hardly high enough to justify conclusions as to breeding, it seems unlikely that Rhizopertha could survive for very long in wheat of 6 per cent. moisture content stored in a dry atmosphere. In Culture 90 the grain was only slightly damaged at the end of 55 days.

[After this Report was sent in another examination of Cultures 85–90 was made, on 18th July, 1919, with rather unexpected results, showing how careful one has to be in drawing conclusions as to the complete extermination of weevils. In Culture 85, 18 live adult *Calandra oryzæ* were found; in Culture 86, 7 live and 17 dead *C. granaria*; in Culture 87, 69 live and 17 dead Rhizopertha. Cultures 88 and 89 yielded no weevils, and Culture 90 yielded 17 live and 21 dead Rhizopertha. Though interesting from a biological point of view these later results hardly affect our practical conclusions.]

V. Effects of the Insects upon Wheat.

The most complete observations that we have made upon the destructive effects of the insects upon the wheat are those in connection with Culture 25 (*Calandra oryzæ*), where our observations extend over 14 months. One hundred and sixty grams of soft Australian wheat (18A), having a moisture content of about 12 per cent., were infected with 100 weevils on February 5th, 1918, and kept at room temperature. By June 18th the number of loose live adults had fallen to 18 and the grain had hardly been affected. By October 5th the number of loose live adults had increased to 332. The grain was dry, not caked, not mouldy and only very slightly mitey. After being sifted to free it from fæcal matter, etc., it was found to have lost 10·81 grams in weight, or about 6·75 per cent. By December 16th the number of loose, live adults had increased to 617. The grain was still dry, but a little caked below, though not firmly; not mouldy, but much gnawed and with a good deal of dust. After sifting it weighed 137·09 grams, showing a loss of 22·91 grams, or 14·31 per cent. By April 11th, 1919, the number of loose live adults had again fallen to 18. The grain was caked at the bottom for about one-third up. It was still dry, with a good deal of dust, but very slightly mildewed. It weighed, after sifting, 128·89 grams, showing a loss of 31·11 grams from the commencement of the experiment, equivalent to 19·44 per cent. The total damage, however, was much greater than is represented by these figures, for a very large proportion of the grains, perhaps half, contained live advanced larvæ (*see* p. 44), and much of the grain that remained was merely the outer covering or pericarp. In fact, it was probably almost worthless for milling purposes.

In addition to the direct damage which the weevils do to the wheat by consuming the "kernels," they also foul it very badly with their fæces, which take the form of a greyish powder, seen, under the microscope, to consist of oval or moniliform pellets. These fæcal pellets appear to form a very suitable medium for the growth of fungi, for, in a moist atmosphere, wheat that is badly fouled becomes very damp and mouldy, and is converted in the course of a few weeks or months into a dark-coloured, decaying mass, caked together and giving off a strong ammoniacal smell. The hygroscopic properties of this substance are probably due in a large measure to the fæcal matter. These changes take place in wheat attacked by either species of weevil, and even in the ordinary laboratory atmosphere, at room temperature, if sufficient weevils are present. They are probably promoted by rise of temperature in the wheat caused by the presence of the insects themselves, as described on p. 8, and by "heating" of the wheat, due to fermentation as soon as it becomes sufficiently moist. With large quantities of wheat the "heating" factor is doubtless of great importance. In a dry atmosphere, however, such as we had in incubator No. III (at a temperature of about 71° F.) weevilly wheat does not rot, though it becomes more or less caked and very dusty.

In the absence of insects the wheat, if fairly dry to start with, though in a moist incubator, may remain for more than 12 months without becoming mouldy and rotten, though a great many mites may make their appearance in it.

The effect of Rhizopertha upon the wheat is somewhat different, for no matter how badly infected, the wheat rarely becomes damp and rotten, even in a moist atmosphere. Indeed, we have only one record of this having occurred, viz., in Culture 76, with artificially dried wheat.

It is well known that the adult Rhizopertha attacks the wheat in a somewhat different way from Calandra, " milling " a great quantity of flour which it does not, at any rate immediately, consume, and in an old culture the wheat becomes almost entirely reduced to a light grey, dusty powder, with a layer of empty husks (pericarps) on top, which would also probably be reduced to powder in time. A description, taken from our notes, of such a culture, about 11 months old, in a glass cylinder, reads as follows :—" On the top a layer of thin, empty, much perforated husks, about 15 mm. deep, free from dust. Below this a layer of grey powder (nearly white) about 70 mm. deep, which proved, on being turned out, to contain numerous partially eaten grains and some husks, the lower part lightly caked but easily powdering and still containing numerous partially eaten or even sound grains. The whole dry, free from mould or mildew, without much smell. Beetles still numerous." This culture had been kept in a moist atmosphere at a temperature of 86-89° F. In another similar case the culture was observed to have a strong ammoniacal smell.

VI. Summary of Results.

1. Under suitable conditions of temperature and moisture and with an abundant supply of wheat, *Calandra oryzæ* and *C. granaria* show a very high rate of increase and breed all the year round.

2. The optimum temperature for the breeding of *Calandra oryzæ* and *C. granaria* is about 82° F., for *Rhizopertha dominica* somewhat higher.

3. At all temperatures and under all conditions, when breeding takes place at all, *Calandra oryzæ* increases much more rapidly than *C. granaria*, the maximum observed for the former species being a 700-fold increase in 16 weeks, at an average temperature of 82·5° F. For this reason *C. oryzæ* is a more serious danger than *C. granaria*, unless, indeed, in this country, the higher rate of increase is counterbalanced by the higher death-rate of the adults in winter.

4. At ordinary room temperatures in this country both *Calandra oryzæ* and *C. granaria* multiply only during the warmer months of the year, the lower temperature limit for multiplication being probably about 65° F., while for *Rhizopertha* it is probably about 70° F.

5. At ordinary room temperatures nearly all adults of *Calandra oryzæ* are killed off during the winter, but large numbers of larvæ survive in the interior of the grains. The adults of *Calandra granaria*, on the other hand, survive the winter in large numbers, the death rate being little, if any, higher than at other times of the year.

6. The adults of the three species show remarkable differences in their susceptibility to cold. After being kept at a temperature of 33–36° F. for 11 days, 91 out of 100 *C. granaria* recovered, only 3 out of 100 *C. oryzæ* showed very feeble signs of life, and none out of 100 *Rhizopertha dominica* recovered.

7. *Rhizopertha dominica* is less susceptible to high temperatures than the two weevils, the lethal temperature for an exposure of three minutes being about 146° F. for the former and between 120° and 131° F. for the latter (in the adult condition).

8. An exposure to a temperature of 145·5° F. for five minutes is sufficient to kill the larvæ of *Calandra oryzæ* and probably to sterilize the wheat completely as regards all insect life.

9. Although a moist atmosphere is undoubtedly more favourable than a dry one for the two weevils, both species can live and multiply in a dry incubator, *Calandra oryzæ* increasing much more rapidly than *C. granaria*, provided the initial moisture content of the grain is sufficiently high.

10. Very dry wheat is less liable to attack by weevils than wheat with a moderate or high moisture content, but wheat readily absorbs moisture in a damp atmosphere, and thereby becomes much more susceptible to weevilling.

11. Rhizopertha can withstand dry conditions better than either of the two weevils.

12. *Calandra oryzæ* and *C. granaria* are both likely to be serious pests in this country, but little is to be feared from *Rhizopertha dominica* under ordinary temperature conditions.

13. In addition to the damage done by actual consumption of the grain the presence of weevils results in extensive fouling with fæcal matter, encouraging the absorption of moisture and the ultimate rotting of the whole mass. In large quantities of wheat the process of decay is doubtless accelerated by rise of temperature due partly to the presence of insects and partly to "heating" of the wheat.

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CONTENTS.

I. Bionomic, Morphological and Economic Report on the Acarids of Stored Grain and Flour.—Part II. By Prof. R. Newstead, F.R.S., and H. M. Morris, M.Sc.

II. Report on the Non-Parasitic or Forage Mites. By Prof. R. Newstead, F.R.S., and H. M. Morris, M.Sc.

III. Appendix. Clinical Notes on the Non-Parasitic or Forage Mites. By Capt. W. N. Pillers, F.R.C.V.S.

I.—BIONOMIC, MORPHOLOGICAL AND ECONOMIC REPORT ON THE ACARIDS OF STORED GRAIN AND FLOUR—PART II.

By R. NEWSTEAD, F.R.S., Professor of Entomology in the University of Liverpool, and H. M. MORRIS, M.Sc. (Manch.).

TABLE OF CONTENTS.

PAGE

INTRODUCTION 4

PART I.—MORPHOLOGY AND BIONOMICS.

Tyroglyphus longior 5
Histiogaster entomophagus 6
Glyciphagus fuscus 10
Aleurobius farinæ 11

PART II.—ECONOMIC AND EXPERIMENTAL.

Acarids in flour 11
Effect on mites of varying moisture content of flour 11
Lethal temperature 12
Effect of hermetical sealing 12
Effect of sifting infected flour through sieves of bolting-silk ... 12
Effect of carbon dioxide on mites... 13
Prevention and remedies 13

CONCLUSIONS 14

REFERENCES 14

INTRODUCTION.

This Report is a record of further research upon the acarids of flour and other farinaceous materials, an investigation of which the first results have already been published in the Royal Society's *Reports and Memoranda of the Grain Pests* (*War*) *Committee* (1917–1918).

In the earlier Report by Newstead and Duvall (1918), the only acarid recorded from flour was *Aleurobius farinæ*. A more extended search has, however, revealed the presence of the following additional species :—*Tyroglyphus longior*, Gervais; *Histiogaster entomophagus*, Laboulbène; *Glyciphagus fuscus*, Oudemans; and *Cheyletus eruditus*, Schrank. Of these four species the first two are of primary importance as they are capable of causing considerable damage to stored flour; but they appear to be much more localized in their distribution, and therefore less destructive generally, than *Aleurobius farinæ*. It appears to us that the injury caused by *Glyciphagus fuscus* is negligible, as in captivity the females, although amply supplied with food, were markedly less prolific than any of the other Tyroglyphids under observation. The predaceous *Cheyletus eruditus* occurred sporadically, but its presence did not appreciably check the ravages of those Tyroglyphids with which it was associated.

This Report is divided into two parts. The first deals with the morphology and bionomics of the species of acarids discovered in flour since the publication of the earlier results; the second with the experimental work in connexion with the preventive and remedial measures undertaken against the species enumerated.

PART I.—MORPHOLOGY AND BIONOMICS.

TYROGLYPHUS LONGIOR, Gervais.*

The resemblance of this species to *T. siro*, Linn., is so remarkably close as to render its separation from the latter a task of extreme difficulty. This separation is apparently based on slight variations in the external characters, but those given by Michael (1903) for the differentiation of the two species do not seem to be entirely satisfactory. In the first place, the plumose hair which he figures and describes as being attached to the femur of the second leg of *T. siro*, is actually situated at the margin of the body immediately behind the level of the insertion of the first leg, in a precisely similar manner to the plumose hair in *T. longior* and *Aleurobius farinæ*. Michael's other distinguishing features are tabulated below.

——	*T. longior.*	*T. siro.*
Body hairs	pectinated	simple.
Spines at distal end of tarsus	absent	two or more.
Length of tarsus ...	longer than two preceding segments	equal to or less than the genual and tibia together.

In specimens of *T. siro* from the collections of the Liverpool University, identified by Michael, some, at least, of the body hairs are pectinated like those of *T. longior*. Both species also have spines at the distal end of the tarsi, and such spines are shown by Canestrini (1888) to be present in *T. longior*. Among a number of specimens of *T longior* from the collection of A. Berlese, some have the typically long tarsus, others a relatively short one as in *T. siro*.

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* For a figure of this species *see* Plate VI, figs. 29, 30.

A possible difference between these two species is the presence in *T. siro* of a chitinous bar immediately posterior to the vulva of the female, which appears to be absent in the case of *T. longior*.

HISTIOGASTER ENTOMOPHAGUS, Laboulbène.

(Plates I–III, Figs. 1–15.)

A description of this species is given below in each stage of its development, with the exception of the hypopial nymph, of which we found no example.

Male (figs. 1, 2, 3). In *form* the young adults are generally more narrowly elongate than the older examples, and have the sides of the abdomen nearly parallel; the ratio of the length to the breadth is 5 : 2. In older specimens the abdominal region is relatively larger and much more ovate in outline, and is truncated posteriorly. In all examples the cephalo-thoracic constriction is strongly marked. Integument more or less shiny; in certain lights the sublying fat bodies may give it a finely granular appearance. *Colour* translucent white; legs and capitulum faintly dusky yellowish or red-brown.

Chetotaxy.—The hairs of the dorsum are arranged as follows: a short pair arising close together immediately behind the capitulum, their tips projecting beyond the mandibles; a second very long pair above the insertion of legs II and towards the margin; a third pair at or near the margin at the centre of the space between legs II and III; a fourth pair marginal, arising a little in advance of the centre of the space between leg IV and the commencement of the "shelf" or flattened extension of the abdomen; the fifth pair occupying a subcentral position near the junction of the abdomen with the "shelf." On the ventral surface there is a hair on either side of the sternum and a transverse series of four short hairs lying between legs III; there are also four similar hairs in a line with the anterior pair of copulatory suckers; the anal suckers with two pairs of supplementary hairs are situated slightly anterior to the base of the "shelf." The "shelf" itself is furnished ventrally with one pair of very long hairs.

The arrangement of the hairs on the legs is as follows: *Leg I* (fig. 10) with a moderately long hair on the femur; four on the genual, the longest of which reaches to the tarsus; tibia with two, one of them of great length, being more than twice the length of the tarsal segment; tarsus with five, one of which is short, stout and bluntly pointed at the tip. The hairs on *leg II* (fig. 11) are arranged in a similar way to those on leg I, and their relative lengths are also similar, except that there are only three hairs on the genual. *Leg III* (fig. 12) has one relatively long hair on the coxa, a slightly shorter one and a very long one on the tibia, and four on the tarsus, the longest of which is about equal in length to the longest hair on the tibia of legs I and II. *Leg IV* (fig. 13) has one relatively long hair on the femur and two on the tibia, the longest of which is greater in length than the tarsal segment; the tarsus has four hairs, two short ones, one about three times the length of the shortest, the fourth very long and similar to that on the tarsus of leg III.

Mouth parts.—*Mandibles* (fig. 6) robust with the proximal portion strongly incrassate. Chelæ with four teeth above and three below. *Palpi* (figs. 7, 8, 9) of three segments: the proximal one much the longest; second segment one-third the length of the first, with one fairly long outstanding hair; the third segment is a little shorter than the second, and has the tip partly divided so that the structure appears to be faintly chelate. Apex with two subterminal hairs, one of which, the shorter, is rather strongly curved, of uniform width throughout and bluntly pointed at the tip. *Maxillæ* (figs. 6, 7).—These structures consist of two thin lanceolate processes, one of which, when displaced as shown in fig. 9, appears to have three extremely minute, closely adpressed, dactyliform appendages. These processes are fused with the inner edge of the distal portion of the first segment of the palpus. The ventral plate is deeply divided in the median line in front on the ventral surface, but less so on the dorsal. The hypostome is triangular.

Epimera.—The first pair are united to the sternum, the others free.
Length: 0·35–0·42 mm.; *breadth:* 0·14–0·18 mm.

Female.—The *form* varies with age as in the case of the male. The "shelf" of the abdomen is absent, and the end of the abdomen is slightly pointed. The cephalo-thoracic constriction is well marked in the young form, but less so in old adults.

The *chetotaxy* of the dorsum and legs is similar to that of the male. On the ventral surface there is a hair on either side of the sternum, and a transverse series of four short hairs lying between legs III; there are also two pairs of similar hairs beside the vulva, one pair anterior to the other. The long pair of hairs corresponding to those on the ventral side of the "shelf" of the male are situated in the female at the end of the abdomen. On each side of the anus near its anterior end there is a hair of medium length.

The vulva, which is situated between the epimera of legs IV, appears as a V-shaped opening, the V being directed forward; the arms are chitinized and very close together for the basal half of their length. The anus is a narrow opening with slightly projecting lips extending from rather more than half-way between the vulva and the end of the abdomen, beyond which the lips project as a slight median point.

Between the fifth pair of dorsal hairs there is a pair of campanulate pits similar to, but larger than, those from which the hairs arise, and their external rim is not nearly so strongly chitinized as that of the little cup to which the hairs are attached. Whether these structures are tactile in function, or whether they are glandular pores, it is not possible to say. They are much more readily observed when the specimen is mounted in profile than when it is in a dorso-ventral position. In the latter case the distance between the pits is one-third of the distance between the pair of hairs. Slightly above the centre of the space between the two long hairs on the posterior end of the abdomen, and lying immediately above the posterior end of the anal lips, is a minute blunt projection which is probably a rudimentary bursa copulatrix. *Length:* 0·49–0·53 mm.; *breadth:* 0·19–0·22 mm

The *Expulsory vesicles* or *Oil-glands* are very conspicuous lying in a dorso-lateral position in the abdomen, posterior to the fourth pair of legs. Each vesicle is rather ovoid in shape, is colourless and contains a highly refracting liquid. They communicate with the exterior by a short, narrow tube, the exterior end of which is surrounded by a chitinized ridge. This opening lies above the vesicle near its anterior end.

Receptaculum seminis. In examining mounted female specimens of *Histiogaster entomophagus* a rather striking internal structure is noticed lying in about the median line near the posterior end of the body, its position varying slightly under pressure. This structure (fig. 14) is bell-shaped and is part of the receptaculum seminis. The tube from the bursa copulatrix joins the receptaculum seminis at the top of this structure, while the tubes from the receptaculum seminis to the ovaries arise beside this tube, near the top of the structure. The structure itself and the bases of the tubes to the ovaries are strongly chitinized, although the remaining parts of the tubes and also the receptaculum seminis have very thin and delicate walls. The chitinized portion of the tubes to the ovaries has the form shown in the figure.

A number of other species of Tyroglyphidæ have been found to possess a structure in connection with the receptaculum seminis which is clearly homologous with that of *Histiogaster entomophagus*, although differing from it in various ways.

In *Histiogaster carpis*, Kr., the structure is much narrower, with a branch on each side from which the tubes to the ovaries arise. In *Glyciphagus spinipes*, Koch, the bases of the tubes to the ovaries are of the same shape as in *Histiogaster entomophagus*, but although they arise almost as closely together as in that species, with the tube from the bursa copulatrix between them, the only parts chitinized are the proximal portion of the tubes and a very small part of the wall of the receptaculum seminis round the point of origin of each tube. In *Aleurobius farinæ*, De Geer, the structure is bell-shaped, but relatively rather short, and the corresponding parts are chitinized as in *Histiogaster entomophagus*; in addition, the tube from the bursa copulatrix to the receptaculum seminis appears to be slightly chitinized. The tubes to the ovaries arise at the base of the structure. In *Rhyzoglyphus echinopus*, Fumouze and Robin, the bases of the tubes from the receptaculum seminis to the ovaries are again of the same shape and are chitinized. These tubes appear to arise from a small chitinized plate forming part of the receptaculum seminis, to which the tube from the bursa copulatrix appears to be attached. *Chortoglyphus arcuatus*, Troupeau, appears to have a somewhat similar structure.

Nymph (Fig. 5).—The *form* is similar to that of the female and varies similarly with age. The *chetotaxy* is also similar to that of the female. There appear to be two distinct sizes of nymphs, probably indicating two stages of development. The only external indication of the reproductive organs is a small oval area between the coxæ of legs IV in the second-stage nymph, enclosing four minute disc-like structures. In the first-stage nymph two of these minute structures are seen without the enclosing oval. *Size.*—Smaller form: *length*, 0·23–0·25 mm.; *breadth*, 0·09–0·10 mm. Larger form: *length*, 0·27–0·32 mm.; *breadth*, 0·11–0·13 mm.

Larva.—The *form* of the hexapod larva is also similar to that of the adult female and nymph, the width again varying with the age. It bears one transverse row of four hairs ventrally, between the coxæ of legs III. The pair of hairs beside the anus of the nymph appears to be absent from the larva, and also those arising dorsally on the posterior end of the abdomen. The sternum is more slender than that of the nymph, and between the coxæ of the first and second pairs of legs, a pair of "bruststiele" are situated. The latter have the form of short, round, blunt tubercles. *Length*, 0·15–0·19 mm.; *breadth*, 0·07–0·09 mm.

Ovum.—The egg is elongate, the ratio of length to breadth being similar to that of the adult, namely, 5 : 2. It is white and has a smooth and apparently structureless covering. *Length*, 0·15; *breadth*, 0·06 mm.

Histiogaster entomophagus lives amongst the flour in the same way as *Aleurobius farinæ*. It has not been found to multiply so rapidly as that species, but is capable of causing similar damage to flour and of rendering it unfit for use. It was in flour that had been kept for a considerable time that this species was found three out of four times. On the first occasion it occurred plentifully in a number of jars of flour which had been used for experiments a year or more previously. Whether the acarid had been in the flour during the experiment and had escaped detection, or whether it had entered the jars subsequently is not known.

Histiogaster entomophagus also occurred in a sample of "mitey" flour received from a flour mill. In this case the flour was stated to have been "milled some months previously."

A sample of some flour which had been exported from this country to West Africa in 1906 in what were stated to be hermetically sealed tins, was returned to this country for examination four years later, and was found by us to be heavily infected by *Histiogaster entomophagus*. The flour had a most unpleasant odour, was rather dark in colour and quite unfit for human food owing to the large percentage of fæcal matter in it.

The fourth occasion on which *Histiogaster entomophagus* was encountered was in a sample of poultry meal, in which it was associated with *Aleurobius farinæ*. This meal, which was of very poor quality, was heavily infested with the mites, *Aleurobius* being the more numerous.

Excessive moisture appears to favour the propagation of *Histiogaster entomophagus*. It was also found that individuals of this species, in all stages of development, were able to live for as long as eight weeks floating on the surface of water, and for about two weeks when entirely submerged in the same medium.

GLYCIPHAGUS FUSCUS, Oudemans. (Plates IV and V, Figs. 16–26.)

This mite was found in only one sample of flour, which had been purchased for use in our experiments. It occurred very sparingly, but examples of both sexes were obtained; the rapid increase of *Aleurobius farinæ*, with which it was associated, rendered it very difficult to find the former species. This mite is stated by Oudemans (1903) to have occurred in meal, and it is recorded by him from the Netherlands and from France.

Form.—Both sexes are ovoid in shape, with the ventral surface flattened, and the dorsal surface somewhat convex. The cephalothoracic constriction is very slightly marked, in the mid-dorsal region only. The *colour* pale brown, with the legs and epimera of a darker shade.

Male.—On the dorsal surface there is a pair of rather short, finely plumose hairs, placed close together immediately behind the capitulum; a second pair near the margin, above the coxæ of the second pair of legs; two pairs in line between the second pair and the median dorsal line; a shorter pair of hairs near the margin above the coxæ of legs IV, with a pair of simple hairs between them. At the posterior end of the abdomen are a number of short, stout hairs which are curved downwards. On the ventral surface there is a hair on either side of the sternum; a plumose hair between the coxæ of legs II and III; a hair between the third and fourth epimera; a pair behind the fourth epimera, near the median line; a second pair farther back and rather more widely separated; and a third pair nearer to the median line. The first epimera are fused to the sternum, the second are free, and the third are fused at their inner end to the fourth. *Length*, 0·30 mm.; *breadth*, 0·17 mm.

Female.—The sternum and epimera form a ring around the vulva, all the epimera being joined to the ring. The arrangement of the hairs on the ventral surface is as follows:—A pair of hairs behind the first epimera; a pair at the point of contact of the second epimera with the ring; a hair between the third and fourth epimera, and another just inside the ring where these epimera join it; a short one posterior to the ring, and two pairs immediately anterior to the anus. *Length*, 0·39–0·42 mm.; *breadth*, 0·25–0·27 mm.

The *chetotaxy* of the legs in both sexes is clearly shown in the figures.

The following points of difference were noticed between our specimens of *Glyciphagus fuscus* and Oudemans' descriptions and figures.

The tarsi of legs III and IV in Oudemans' figure of the male are shown as rather pointed, which we did not observe in our specimens. The positions of the pectinated hairs are similar, except that of leg III, which is described by Oudemans as being situated on the tarsus, ventrally, distally and inwards. This hair was found by us on the tibia, ventrally, medianly and inwards, in which position it is shown in his figure. There are considerably more hairs, however, than Oudemans described, as he has noted only those most strongly pectinated. The cup-like shape of the femur of legs I and II of the female is quite distinct in our specimens, but that of the genual and tibia is not so well marked. The lateral margins of the female are figured by Oudemans as being strongly serrated; this was not observed in our material.

ALEUROBIUS FARINÆ, De Geer. (Plate VI, figs. 27, 28, 31–34.)

In the previous Report (1918, p. 6), attention was drawn to the discrepancy in Michael's account of the genital suckers of this species. At that time it was thought that these organs were present in the males only, as Michael had stated them to be in his description of the species. Further examination has shown, however, that the genital suckers are present in both sexes.

PART II.—ECONOMIC AND EXPERIMENTAL.

ACARIDS IN FLOUR.

Aleurobius farinæ is the only acarid with which we have experimented, as it is by far the most important, and any treatment which would be effective against this species would probably also prove effective against the other species which may occur, or would at least prevent them from being able to cause any appreciable damage.

EFFECT ON MITES OF VARYING MOISTURE CONTENT OF FLOUR.

In the previous series of experiments it was found that the minimum amount of moisture necessary to the existence of mites in flour was between 11·5 per cent. and 12·5 per cent.

In the following experiments the percentage of moisture was ascertained by drying about 5 grams of the flour in a steam oven for 24 hours. It is necessary clearly to state the method employed owing to the different results obtained when other methods are adopted.

The results obtained in these experiments were briefly as follows:—

In flour with a moisture content of 13·0 per cent. the mites increased rapidly in numbers; with a moisture content of 12·4 per cent. the increase was relatively very slow; with a moisture content of 12·2 per cent. they died out in two or three weeks, but the surface of the flour indicated that their destruction was gradual. In flour with a moisture content below this figure the mites perished quickly.

It is thus shown that the minimum moisture content necessary to the existence of the mites is about 12·3 per cent.; so that if 11·0 per cent. be taken as the maximum percentage of moisture permissible in stored flour there is a small margin of safety.

LETHAL TEMPERATURE.

The experiments previously carried out to determine the lowest temperature which is fatal to the mites were repeated and a similar result obtained, namely, that 120° F. for about 12 hours is the minimum temperature required for the destruction of all mites and eggs.

EFFECT OF HERMETICAL SEALING.

These experiments were also repeated with results similar to those obtained previously, it being found that even after a jar had been hermetically sealed for over two months a few mites reappeared in the flour, although care had been taken to avoid re-infection.

EFFECT OF SIFTING INFESTED FLOUR.

A series of experiments were carried out to test the effect of passing infested flour through sieves of bolting-silk. For this purpose a set of sieves were obtained, composed of bolting-silk of varying degrees of fineness:—

A,	composed of	No.	6	bolting-silk,	74	meshes	per lin. inch.
B	,,	,,	8	,,	86	,,	,,
C	,,	,,	9	,,	97	,,	,,
D	,,	,,	10	,,	109	,,	,,
E	,,	,,	12	,,	125	,,	,,
F	,,	,,	14	,,	139	,,	,,
G	,,	,,	16	,,	157	,,	,,
H	,,	,,	20	,,	173	,,	,,
I	,,	,,	25	,,	200	,,	,,

On microscopic examination of the sifted flour, it was found that large numbers of the adult mites were removed by the coarser sieves, but that many larvæ and eggs passed through sieves G and H, while a few larvæ were also seen after passing through sieve I; some eggs also passed through this sieve, though they were not detected in the flour. Even the finest sieve was quite ineffectual in removing the fæcal pellets.

A microscopical examination of sieve I showed that there was, as one would have expected, a good deal of variation in the size of the individual meshes, and that the larger meshes were of a size to allow the passage of an egg lengthways or of a newly hatched larva, although a considerable percentage of the flour itself would not pass through the sieve.

Heavily infested flour which is passed through sieve F (No. 14 bolting-silk, 139 meshes per linear inch) or sieve G (No. 16 bolting-silk, 157 meshes per linear inch) will, for a time at least, show few signs of mites; but on microscopic examination the previous infestation will be immediately apparent, owing to the great amount of fæcal matter left, even if no mites are actually observed. It would not be possible to keep such flour for any length of time, as, although there might be no mites present, the presence of the fæcal matter is very conducive to decomposition, owing to its absorbing moisture and being the probable source of the bacteria which are instrumental in causing the final degeneration of the flour.

EFFECT OF CARBON DIOXIDE ON MITES.

The question was considered of treating infested flour with gases in order to bring about the destruction of the mites, and carbon dioxide was chosen as one likely to destroy the pests without injury to the flour, and to permit of treatment being carried out at a moderate cost.

Treatment with carbon dioxide did not give satisfactory results. Flour was stored in an atmosphere of almost pure carbon dioxide for various periods of time up to 50 hours, but in each case the same result was obtained. All movement of the mites in the flour ceased in a few minutes, but when the flour was again exposed to air the mites recovered, and in a short time many of them were again active; it therefore appears that, to be effective, the carbon dioxide must be present during the whole time the flour is in storage.

Carbon bisulphide has been found by Miss Eales (1917) to be effective in destroying cheese mites, but its poisonous properties render it unsuitable for use with flour.

PREVENTION AND REMEDIES.

It is obvious that preventive measures of control are more desirable than remedial measures, owing to the production of large quantities of fæcal matter which it is impossible to eliminate from the flour.

The most satisfactory method of preventing infestation by mites is to store only flour the moisture content of which is below 11 per cent., or the equivalent percentage reached by other methods of determination. This percentage of moisture is lower than that ordinarily contained in flour, the usual amount present in commercial samples being between 12·5 per cent. and 14 per cent. It would thus be necessary to submit to a drying process any flour which it was intended to store for any length of time, in order to render it mite-proof. That this would be a relatively simple matter is indicated by the test on the drying of wheat by a method similar to that of the "Hess Drier and Cooler" which was described in the previous Report. In the instance noted, the moisture content was decreased 1·4 per cent. in the ten minutes during which the wheat was exposed to a temperature of 140° F. Flour would dry more rapidly than wheat, and the process would be far more satisfactory than an attempt to destroy mites by heat alone. It would have the additional advantage of preventing reinfestation, which very easily occurs in flour which has merely been heated in order to kill the mites, without, probably, greatly reducing its moisture content.

Moreover, exposure to a high temperature for the number of hours necessary to destroy the mites, has a tendency to cause the flour to cake. So long as flour which had once been dried was kept in a dry place, there would be little possibility of reinfestation.

CONCLUSIONS.

(1) In addition to *Aleurobius farinæ*, *Histiogaster entomophagus*, *Tyroglyphus longior*, and possibly *Glyciphagus fuscus*, are capable of damaging flour in storage.

(2) A relatively high moisture content in both wheat and flour is essential for the existence of the various species of acari.

(3) Preventive measures are far more satisfactory than remedial measures.

(4) Attacks by mites may be prevented by storing only flour the moisture content of which is below 11 per cent. in the temperate zone, and a much lower percentage in tropical countries.

(5) The storing of uninfested flour in hermetically sealed receptacles would no doubt be efficacious if properly carried out; but our experiments show that if the flour is already infested with mites some may survive even after hermetic sealing for over two months.

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EXPLANATION OF PLATES.

Plate I.

Histiogaster entomophagus.

Fig.
1.—Male. Ventral aspect. × 175.
2.—Male. Lateral aspect. × 175.

Plate II.

Histiogaster entomophagus.

Fig.
3.—Male. Dorsal aspect. × 175.
4.—Larva. Ventral aspect. × 280.
5.—Nymph. Ventral aspect. × 280.

Plate III.

Histiogaster entomophagus.

Fig.
6.—Mandible. × 375.
7.—Hypostome, ventral aspect. × 375.
8.—Hypostome, dorsal aspect. × 375.
9.—Maxillary palp. × 375.
10.—Leg I, ventral aspect. × 375.
11.—Leg II, ventral aspect. × 375.
12.—Leg III, ventral aspect. × 375.
13.—Leg IV, ventral aspect. × 375.
14.—Chitinized portion of receptaculum seminis; (*bc*) tube from bursa copulatrix; (*o*) tube to ovary. × 850.
15.—Ovum. × 175.

Plate IV.

Glyciphagus fuscus.

Fig.
16.—Female. Ventral aspect. × 165.
17.—Male. Ventral aspect. × 165.

Plate V.

Glyciphagus fuscus.

Fig.
18.—Mandible. × 375.
19.—Hypostome, dorsal aspect. × 375.
20.—Leg I of female, ventral aspect. × 270.
21.—Leg II of female, ventral aspect. × 270.
22.—Leg III of female, ventral aspect. × 270.
23.—Leg IV of female, ventral aspect. × 270.
24.—Leg IV of male, ventral aspect. × 270.
25.—Ovum. × 375.
26.—Hair on tibia of Leg II of female. × 850.

II.—REPORT ON THE NON-PARASITIC OR FORAGE ACARI OF THE FAMILY *TYROGLYPHIDÆ.*

By R. NEWSTEAD, F.R.S., Professor of Entomology in the University of Liverpool, AND H. M. MORRIS, M.Sc. (Manch.).

The term "Forage Acari" is usually applied to all acarids or mites of a non-parasitic nature which are found living upon the domesticated animals, or in association with the hay, grain, meal, bran, or other forage with which the animals are fed.

In microscopical examinations of skin-scrapings from the horse and other domesticated animals these non-parasitic acari have often been mistaken for mange acari, and not infrequently this has led to unnecessary isolation and treatment of the temporary host. On the other hand, their presence in the forage may necessitate its ultimate destruction.

Although the importance of being able accurately to distinguish between the true parasitic acari and those occurring accidentally on the skin has long been recognized, no definite effort has apparently been made in this direction, although a number of scattered records exist of the occurrence of various species on the skin of animals and in skin-scrapings, when they have been described as "accidental acari" or "forage acari."

Several species of acarids commonly occur in forage of different kinds, frequently in considerable, and occasionally in enormous, numbers; hence it is only to be expected that a certain number of individuals should find their way on to the skin of animals which are fed on mite-infested forage. Another method by which mites are enabled to reach the skin of the animal on which they are found is by means of insects, especially flies. The latter are not infrequently found to have one or more mites—usually in the hypopial stage—clinging to them. These forage acari are usually harmless, but certain species, when occurring in very great numbers, are capable of causing considerable irritation. This also holds good in the case of persons handling substances such as vanilla, sugar, and grain, in which these acari are at times very abundant.

An examination of dust from the beams, ledges, &c., of a stable or barn will usually reveal the presence of remains of many forage acari, if not living specimens, and the dust brushed out of the hair of a healthy animal during grooming will frequently show similar remains.

HISTORICAL.

Fürstenberg (1861) describes and figures an acarid which had been found in immense numbers on the skin of a recently stuffed elephant. He states that, although a parasite, it is not an itch-mite. Gerlach however, held a different opinion, and called it *Symbiotes elephantis.* Fürstenberg's figures of this species show that it is a hypopial nymph, and very probably that of a species of *Tyroglyphus.*

Fleming (1875) remarks that "it is necessary to remember that in the epidermis detritus of all horses, no matter whether the skin be healthy or diseased, there are to be found the bodies of acari derived from the dust of forage, such as *Glyciphagæ*, *Cheyletæ*, *Tyroglyphæ*, etc., which might be mistaken for the sarcopt, although they are perfectly harmless."

Raillet (1895) states that the acarid found by Hering in 1838 on the foot of a horse affected with canker and named by him *Sarcoptes hippodus* was undoubtedly referable to *Glyciphagus domesticus.* Raillet also states that *Tetranychus molestissimus*, which lives on the lower surface of the leaves of *Xanthium macrocarpum*, also attacks warm-blooded animals in Uruguay and in the Argentine.

Garnett (1902) states that on making an examination of a sheep badly affected with scab he found, in addition to *Psoroptes communis* var. *ovis*, another "parasite" which was subsequently determined by Michael as *Glyciphagus domesticus*, De Geer. He states furthermore that he succeeded in keeping this acarid alive "for nearly twelve months on dried sheep-skin." Five microphotographs are given in illustration of his article.

Butler (1914), in his article on sarcoptic scabies of the horse, states that there is a possible source of error in making a microscopical diagnosis, as acari other than those producing scabies are to be found on the skin of the horse, and that "Dermanyssus of the fowl and Pteronyssus of the sparrow or linnet produce great irritation" on the horse. He also records the occurrence of several species of non-parasitic acari in groomings from healthy horses, and states "it is necessary to make accurate observations upon them for they are frequently met with." Twelve figures are given by him in illustration of this paper, among which we recognise as non-parasitic species *Aleurobius farinæ*, the hypopi of two Tyroglyphids (species *non det.*) and the predaceous *Cheyletus eruditus.*

Baudet (1915) records the occurrence of *Glyciphagus destructor*, Schrank = *Glyciphagus spinipes*, Koch in hay, and states that it is often found on horses. He further states that he has found this species in a preparation of "ringworm" from a horse, remarks upon its resemblance to *Chorioptes*, but points out the difference in the structural characters of the legs.

Kirk (1917), whose observations were made in a mange hospital in France, records the occurrence on the horses of many different undetermined forms of "forage acari," of which he figures three:—"Mark I" may represent the hypopial stage of a Tyroglyphid; "Mark II" is a representative of the *Oribatoidea*, as evidenced by the presence of the pseudostigma; "Mark III" cannot be determined with any degree of accuracy.

Carpano (1918) has recorded the occurrence in forage of a mite which caused dermatosis of the lips, spreading to the nose and cheeks, of a horse, and which he considered belonged to the genus *Tyroglyphus*. The mite which he figures is, however, not a Tyroglyphid, but probably a Tarsonemid, and appears to be very similar to *Pediculoides ventricosus*, which is known to occur in wheat and to produce a peculiar form of dermatitis in man, especially in the great wheat-growing regions of Russia.

Newstead and Duvall (1918) refer to the presence of *Aleurobius farinæ* on British army horses in France, and state (p. 34) that "these were no doubt migrants from the fodder and in no sense parasites."

Wadley (1918) states that 14·73 per cent. of the acari found on horses in France during the war, consisted of various species of "forage acari."

Pillers (1919, *a*) notes the occurrence of *Aleurobius farinæ* and also that of several hypopi of the Tyroglyphidæ, (1919, *b*) the common *Tyroglyphus longior*, and (1919, *c*) two hypopi and a Trombidiid; all in equine scrapings. More recently (1920) he has recorded the presence of *Glyciphagus domesticus* in the ear of the domesticated rabbit.

In this account of the "forage acari" it is proposed to deal chiefly with those mites which belong to the family *Tyroglyphidæ*, and very briefly also with their affinities and distinctive characters in relation to the true mange-producing acarids of the family *Sarcoptidæ*. It has been our object to compress into the smallest compass such information as may be of service, and to supplement this with carefully prepared drawings of the important members of both the parasitic and non-parasitic groups.

DIFFERENTIATION BETWEEN "MANGE MITES" (*SARCOPTIDÆ*), AND "FORAGE ACARI" (*TYROGLYPHIDÆ*).

Although there is a considerable difference between these two classes of mites, yet in a casual examination, especially of poor or damaged specimens, they are not easily separable, and it is somewhat difficult to give definite characters which will at all times distinguish all species.

The "forage acari" frequently have the cephalo-thoracic constriction fairly clearly marked, while it is not noticeable in the mange mites (*Sarcoptidæ*). They are also frequently more elongate. The most satisfactory character, however, is the uniformity of the legs, and the form of the caruncle. In the *Tyroglyphidæ* the legs are all similar in structure, and the caruncle is always non-pediculated; while in the mange mites some of the legs are curiously modified, and the caruncle is always borne on a pedicel. Moreover, the claws of the mange mites are stout and fairly straight, with the pedicels attached below them; in the *Tyroglyphidæ* the claws appear to be attached to the caruncle, and they are slender and strongly curved.

TABLES FOR THE DETERMINATION OF "MANGE MITES" OF THE GENERA *PSOROPTES*, *SARCOPTES*, AND *SYMBIOTES*.

A.—All Stages (Larvæ, Nymphs, and Adults).

1. Pedicel of ambulacrous sucker of all legs where present, consisting of three parts *Psoroptes* (figs. 49, 50).
   Pedicel of ambulacrous sucker of all legs where present, consisting of one part only 2
2. Pedicel nearly as long as the leg. Dorsum in both sexes spinose ... ... *Sarcoptes* (figs, 43, 44).
   Pedicel not longer than the tarsus. Dorsum in both sexes not spinose ... *Symbiotes* (figs. 53, 54).

B.—Adults only (Male and Female).

1. Rostrum pointed ... . *Psoroptes* (figs. 49, 50).
   Rostrum blunt 2
2. *Males.*—Leg III bearing a sucker as well as a hair at tip ... ... *Symbiotes* (fig. 53).
   Leg III terminating in a single long stout hair; sucker absent ... ... *Sarcoptes* (fig. 44).
   Females.—Dorsal integument bearing short stout spines ... ... *Sarcoptes* (fig. 43).
   Dorsal integument not bearing short stout spines ... ... *Symbiotes* (fig. 54).

TABLE FOR THE DETERMINATION OF FORAGE MITES (*TYROGLYPHIDÆ*).

1. Leg I of male thickened, the femur bearing a stout spine ventrally ... ... *Aleurobius* (figs. 27, 28).
   Leg I of male not thickened, the femur without a stout spine ventrally ... 2
2. Distinct projecting shelf at posterior end of male; body in both sexes narrowly elongate, with the cephalo-thoracic constriction very clearly marked ... *Histiogaster* (figs. 1–5).
   No protecting shelf in male: body not markedly narrow, the cephalo-thoracic constriction not very clearly marked 3

3. Body hairs all more or less distinctly pectinated ; female with tubular projecting bursa copulatrix	*Glyciphagus* (figs. 16, 17, 35–39)
Body hairs rarely with any trace of pectinations ; no projecting bursa copulatrix	4
4. Base of mandibles covered dorsally by a hood-like projection of the cephalothorax	*Chortoglyphus* (page 22).
Base of mandibles not covered by a hood-like projection	*Tyroglyphus* (figs. 29, 30).

TYROGLYPHIDÆ.

Aleurobius farinæ, De Geer. (Plate VI.)

The body in both sexes is somewhat truncated posteriorly, and is divided by a conspicuous sulcation between the second and third pairs of legs. The legs are all smooth and chitinized, of about equal length. The first pair in the male are markedly incrassate, and have a large tooth-like projection or apophysis on the ventral surface of the third segment or femur (Plate VI, fig. 27). On the other hand, the female (fig. 28) lacks the thickened spine-bearing foreleg, but may be distinguished from the most closely allied species by the character of the hairs at the posterior end of the body, being relatively short and few in number.

This is probably the commonest of the "forage acari" and occurs abundantly in meal of various kinds, bran, "corn" or maize, in addition to wheat, flour, and cheese, &c. Its presence in equine scrapings has already been noted, and judging by the number of examples taken from army horses in France and Flanders, which were submitted to us for determination during the years 1919–20, we may assume that its presence on the horse is of frequent occurrence. It has also recently been found in the ears of a guinea-pig by Pillers.

Histiogaster entomophagus, Laboulbène. (Plate III.)

Body in both sexes narrowly elongate, with the division between the cephalo-thorax and abdomen very strongly marked. Legs relatively short in comparison with the width of the body. Male with a flattened "shelf-like" projection at the posterior end of the abdomen.

We have found this acarid to be a pest of primary importance in connection with the storage of flour and mixed farinaceous foodstuffs, and have dealt with its morphology and bionomics elsewhere (*see* above, p. 6).

GLYCIPHAGUS CADAVERUM, Schrank. (Plate VII.)

Body conical anteriorly, rounded posteriorly; no visible constriction between cephalo-thorax and abdomen. Female with a distinct bursa copulatrix. Easily distinguished by the great length of the numerous body hairs, and by the fact that almost all of them are finely pectinated bilaterally. In life these long hairs render it very conspicuous; and when disturbed its activity is greater than that of other mites observed. We have found it exceedingly abundant in wheat and mixed screenings, chaff, &c.

GLYCIPHAGUS DOMESTICUS, De Geer.

Very similar in its general facies to the former.

It has been recorded by Garnett, and is likely to occur on the skin of animals, especially of those kept in stables, sheds, &c., as it is very commonly found feeding on all kinds of dried animal and vegetable matter, hay, &c. We have recently examined specimens which were found in the ears of a guinea-pig and of a rabbit. (*See* also Pillers, 1920.)

GLYCIPHAGUS ORNATUS, Kramer. (Plate VIII.)

This strikingly characteristic species may be readily distinguished by the large comb-like appendages borne at the distal end of the fourth segment (tibia) of legs I and II of the male.

Our examples were discovered among a number of other acarids found in equine scrapings from army horses in France, which were submitted to us for determination towards the end of 1919.

We have failed to find a record of the occurrence of this species in the British Isles, and its presence here apparently awaits discovery.

GLYCIPHAGUS PLUMIGER, Koch.

Body somewhat angular in outline; dorsum of female with wart-like projections. Body hairs strongly and sparsely pectinated, especially in the female. It is said to occur amongst hay in barns, &c.

GLYCIPHAGUS CANESTRINII, Armanelli.

Distinguishable from *G. plumiger* by the relatively much larger wart-like projections of the dorsum, and by the longer pectinations of the body hairs. Pabulum and habitat similar to those of the preceding species.

We have not been able to secure examples of this species or of *G. plumiger.*

CHORTOGLYPHUS ARCUATUS, Troupeau.

Body oval in shape, truncated posteriorly with no distinct division between the cephalo-thorax and abdomen. Anterior portion of body (cephalo-thorax) forming a distinct hood-like projection over the mandibles. Body hairs very short and confined chiefly to the hind margin.

It has been found in flour and in dust, &c., on the beams and floors of stables and barns.

TYROGLYPHUS LONGIOR, Gervais, AND T. SIRO, Linn.

The affinities of these somewhat variable species and the similarity in general appearance between them has been dealt with elsewhere (*see* above, p. 5). So far as we are able to judge, the slight differences in the external armature of the females are the chief characters by which the two species may be distinguished.

Both species also bear a strong superficial resemblance to the female of *Aleurobius farinæ*, from which, however, they may be easily distinguished by the greater number and length of the hairs at the posterior end of their bodies. The hypopi of both species are commonly met with. Both species have a similar pabulum to that of *Aleurobius farinæ*, and both also have been found in skin-scrapings and groomings from the horse in France and Flanders.

HYPOPI OF THE TYROGLYPHIDÆ.

A large proportion of the "forage acari" which are found on the skin of animals are hypopial nymphs, this stage in the life of the mites being especially adapted for distribution. Many, if not all, of the mites belonging to the family *Tyroglyphidæ* may have a hypopus or hypopial nymph stage in their life-cycle, and, as many members of this family are commonly found in hay, corn, meal, and bran, they are the "forage acari" most usually met with on the skin of animals. The hypopial stage does not occur in the life-cycle of all individual mites, and it is apparently much commoner in some species than in others. The mite while in this stage is more resistant to extremes of heat and drought, is frequently more active than in the other stages, and is in addition provided with an arrangement of suckers near the posterior end of the ventral surface of the body by which it is enabled to cling to some larger and more active mite or insect, and so secure distribution and continuance of the species.

A number of hypopi, representing several species of Tyroglyphid acari, taken from healthy army horses in France and Flanders, have been examined by us from time to time, but owing to the more or less imperfect condition of the material it has not been possible to determine the species with exactitude.

CHEYLETUS ERUDITUS, Schrank. (Plate VIII.)

This extremely interesting acarid, together with all the other members of the family *Cheyletidæ,* may be recognised quite readily by the presence of the very large, pincer-like pedipalps (fig. 42), so distinctly separated from the other mouth parts, and with which the creature seizes and at the same time paralyses its victims. It preys very largely upon those species of Tyroglyphid mites which commonly infest grain, bran, and chaff; which are found also in the dust and screenings in stables, barns, and granaries; and more rarely in or rather on the surface of mite-infested flour. Its presence, therefore, may be considered as strictly beneficial, but we have never seen it in sufficiently large numbers as to reduce to an appreciable extent the swarms of Tyroglyphids.

It has been found by us in groomings from healthy army horses in France and Flanders, and also in the ears of a guinea-pig.

For full details regarding the bionomics and morphology of this acarid, *see* Newstead and Duvall, Royal Society Reports of the Grain Pests (War) Committee, No. 2, 1918, pp. 10–25.

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1919. (*c*) PILLERS, A. W. N. "On the Occurrence of two Hypopi and a Trombidiid in Skin-scrapings of Horses." (*Veterinary Record*, Vol. XXXII, p. 552).
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EXPLANATION OF PLATES.

PLATE VI.

Fig.
27.—*Aleurobius farinæ.* Male, ventral aspect. × 117.
28.—*Aleurobius farinæ.* Female, ventral aspect. × 117.
29.—*Tyroglyphus longior.* Male, ventral aspect. × 117.
30.—*Tyroglyphus longior.* Hypopus, ventral aspect. × 117.
31.—*Aleurobius farinæ.* Tarsus of leg IV of male, side aspect. × 250.
32.—*Aleurobius farinæ.* Egg. × 117.
33.—*Aleurobius farinæ.* Vulva of adult female with genital suckers retracted, ventral aspect. × 250.
34.—*Aleurobius farinæ.* Genital suckers of adult female protruded, side aspect. × 250.

PLATE VII.

Fig.
35.—*Glyciphagus cadaverum* (= *spinipes*). Female, ventral aspect. × 117.
36.—*Glyciphagus cadaverum* (= *spinipes*). Tibia and tarsus of leg II, with sheath slightly displaced. × 250.
37.—*Glyciphagus cadaverum* (= *spinipes*). Egg. × 117.

PLATE VIII.

Fig.
38.—*Glyciphagus ornatus.* Male, ventral aspect. × 87.
39.—*Glyciphagus ornatus.* Tibia and tarsus of leg II, side aspect. × 260.
40.—*Cheyletus eruditus.* Female, ventral aspect. × 87.
41.—*Cheyletus eruditus.* Tarsus of leg I, side aspect. × 325.
42.—*Cheyletus eruditus.* Pedipalp, ventral aspect. × 325.

PLATE IX.

Fig.
43.—*Sarcoptes scabiei* var. *equi*. Female, ventral aspect. × 117.
44.—*Sarcoptes scabiei* var. *equi*. Male, ventral aspect. × 117.
45.—*Sarcoptes scabiei* var. *equi*. Tarsus of leg II of female, side aspect. × 250.
46.—*Sarcoptes scabiei* var. *equi*. Egg. × 117.
47.—*Sarcoptes scabiei* var. *equi*. Portion of dorsal cuticle. × 167.
48.—*Sarcoptes scabiei* var. *equi*. Part of leg IV of male, ventral aspect. × 250.

PLATE X.

Fig.
49.—*Psoroptes communis* var. *equi*. Female, ventral aspect. × 117.
50.—*Psoroptes communis* var. *equi*. Male, ventral aspect. × 117.
51.—*Psoroptes communis* var. *equi*. Tarsus of leg II of female, side aspect. × 250.
52.—*Psorontes communis* var. *equi*. Egg. 117.

PLATE XI.

Fig.
53.—*Symbiotes* (*Chorioptes*) *communis* var. *equi*. Male, ventral aspect. × 117.
54.—*Symbiotes* (*Chorioptes*) *communis* var. *equi*. Female, ventral aspect. × 117.
55.—*Symbiotes* (*Chorioptes*) *communis* var. *equi*. Tarsus of leg II of female, side aspect. × 250.
56.—*Symbiotes* (*Chorioptes*) *communis* var. *equi*. Egg. × 117.

III.—APPENDIX. CLINICAL NOTES ON THE NON-PARASITIC OR FORAGE MITES.

By CAPT. A. W. N. PILLERS, F.R.C.V.S.

During the investigations in connection with the acarids of stored grain and flour, the importance of their relationship to the mange mites and parasitic skin diseases of the domesticated mammals, especially the horse, has gradually made itself apparent. It has long been known that certain species of the usually non-parasitic acari may be found upon the skin of animals, and various interpretations with regard to the clinical importance of such findings have been put forward. During the late war numerous microscopical preparations of forage acari taken from the skins of horses were submitted to me for determination by some of my former students, and the desire for literature upon such acari was frequently felt both at home and abroad.

Wadley (1918), quoting a record compiled by Pallin of the results obtained from the microscopical examination of scrapings taken from a very large number of animals evacuated for mange and contagious skin diseases or as "close-in-contacts," gives the following figures:—

Sarcoptic	46·15	per cent.
Psoroptic	4·57	,,
Chorioptic (symbiotic)	0·83	,,
Demodecic (dermatodectic) ...	4·83	,,
Forage acari	14·73	,,
Lice	1·71	,,
Ringworm	1·81	,,
Negative	24·71	,,
	99·33	per cent.

It must not be assumed that these figures represent the relative frequency of the diseases mentioned in the field throughout the whole period of the war. Unfortunately the exact period during which the investigations were carried out is not given. The date of the publication is January 12, 1918. Although it is not within the scope of the present paper to discuss fully the various figures given by the author, there are one or two points to which attention must be drawn, as they affect the question of the percentage frequency of the so-called forage acari. Presumably the figures do not cover the findings for the years 1914, 1915, and greater part of 1916, but would appear to represent examinations made at hospitals, so that, as ringworm was after a short while treated in the units where it occurred, the percentage findings do not represent the frequency of the disease throughout the war zone. Practically the same remarks apply to lousiness due either to *Hæmatopinus* or *Trichodectes.* Furthermore, cases of chorioptic or symbiotic mange were not generally evacuated to hospital, and, moreover, the wet and mud of the open was not at all favourable to the rapid spread of such a leg-loving parasite. Again, routine skin-scrapings were not taken from all skin cases evacuated from the front during the first years of the war, and there were frequent omissions during the later years. It is well known also that the treatment with lime and sulphur dips proved eminently satisfactory against the *Psoroptes*, and there is no doubt that during the later stages of the war psoroptic mange had been greatly reduced and was quickly disappearing. Sarcoptic mange was therefore much the commoner type of acariasis, although it was kept well under control, as compared with earlier wars. This explains the relatively high findings for *Sarcoptes* (46·15 per cent.) when contrasted with *Psoroptes* (4·57 per cent.). *Demodex* was often found with other mange-producing mites, but as it was comparatively rare, one was always anxious to record a positive finding for this parasite. The low percentage (4·83 per cent.) therefore does not represent fully the demodectic mange present in army horses at the front, as there were quite a number of cases of animals having a double infection of *Sarcoptes* and *Demodex.*

The longer one searches material apparently negative, the more likely is one to come across some form or other of the many acarids which abound in the fodder, beddings, and stable dust, so that 14·73 per cent. is not after all a high figure when one realizes the ease with which such acarids are distributed, and the readiness with which they may adhere to damp serum-exuding skins, or by rubbing, &c.

In routine weekly reports made up at different depôts and taken by variously trained war-time men and non-commissioned officers, a small percentage of error must necessarily creep in.

The grounds for submitting an animal to a test were not the presence of a definite clinical area of skin disease, but usually that there was a small indefinite lesion, that the skin was dirty, or that the animal was rubbing or biting its skin without any visible cause. More important still in this direction was the presence of a positive labial reflex; thus, if when rubbed with the finger-nails, a piece of wood, or a horse-shoe nail, the animal rapidly opened and closed its lips or teeth, it was nearly always sent for examination. The importance of the lip reflex in the many skin and other diseases is worthy of careful research.

The above table, therefore, more truly represents the results of examining the skin of cases such as have been outlined above.

In taking a scraping the hair was usually removed by scissors or clippers over the suspicious area, the dirt removed, and then with a safety-razor blade or thin scalpel material was taken until blood appeared. This material was then boiled for a short while in a 10 per cent. solution of caustic potash, given a few turns in the centrifuge, and examined for acari.

The importance of some of these usually non-parasitic acari upon the skin may be slight, but some may be worthy of prophylactic measures. There is, however, no doubt that their presence upon the skin of horses which answered to the labial reflex cost the country an immense sum during the last two years of the late war.

War-time references to these acari in the veterinary press showed that no serious attempt was made to determine specifically these mites, but that they became known by names similar to those applied by Army Departments to stores, of which there were two or more types. Thus Kirk (1917) adopted a series of diagrams, ranging from "Mark I" to "Mark X" (*see* pages 17 and 18.)

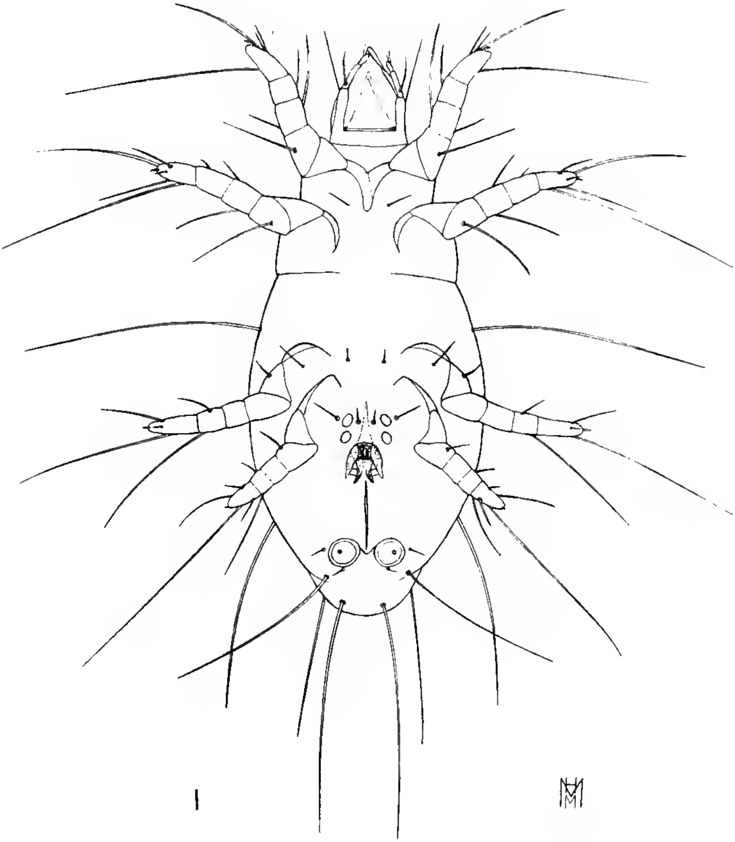
From a national point of view, in times of war there has thus been a close relationship between the acari of grain and those known to be the definite cause of different types of mange. In addition to this, during harvesting, transport, milling, and storage operations, the horse at least comes into closest contact with the acari contained in grain. In all moist conditions of the skin, whether normal or abnormal, accidental acari may adhere to the wet places, but their presence does not necessarily mean that they are the cause of the disease. I have repeatedly liberated a number of living *Aleurobius farinæ* in the mane, tail, and on the withers of my pony without observing any subsequent rubbing or biting.

The Sarcoptids are difficult to find in the early phases of sarcoptic mange, and where it has not been possible to establish their presence on suspected animals samples of food and bedding have been subjected to microscopical examination, with the result that some of the numerous acari found in such materials have been erroneously blamed for the skin disease.

Already as a defence for the presence of un-notifiable mange it has been put forward that the disease was due to acari of forage and that these were easily confused with the true mange mites. It would appear possible also that some of the obscure cases of shaking of the head in horses, sometimes followed by such disastrous results in "run-aways," may be due to forage acari having gained access to the very sensitive lining of the auditory canal. Hay seeds and other grains are usually blamed, but examination often reveals the absence of these.

It is these considerations that give importance to the recognition of these non-parasitic acari which occur more or less accidentally upon the skin of the domesticated animals, and justify the short account of these acarids which is given in the preceding report by Prof. Newstead.

For Bibliography *see* p. 23.



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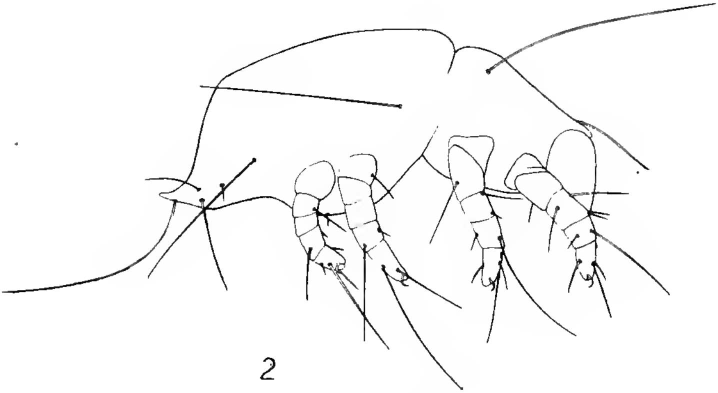

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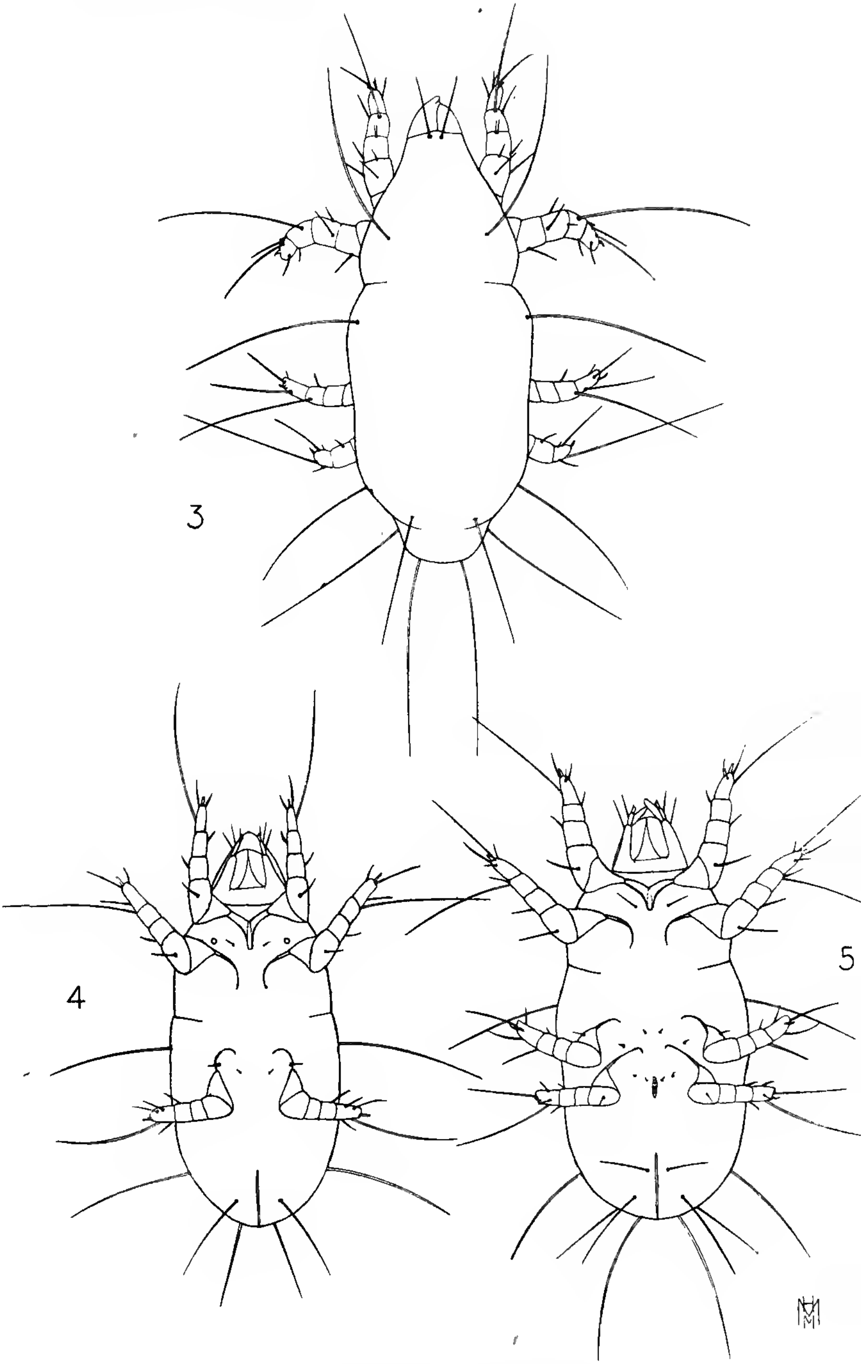
Histiogaster entomophagus.



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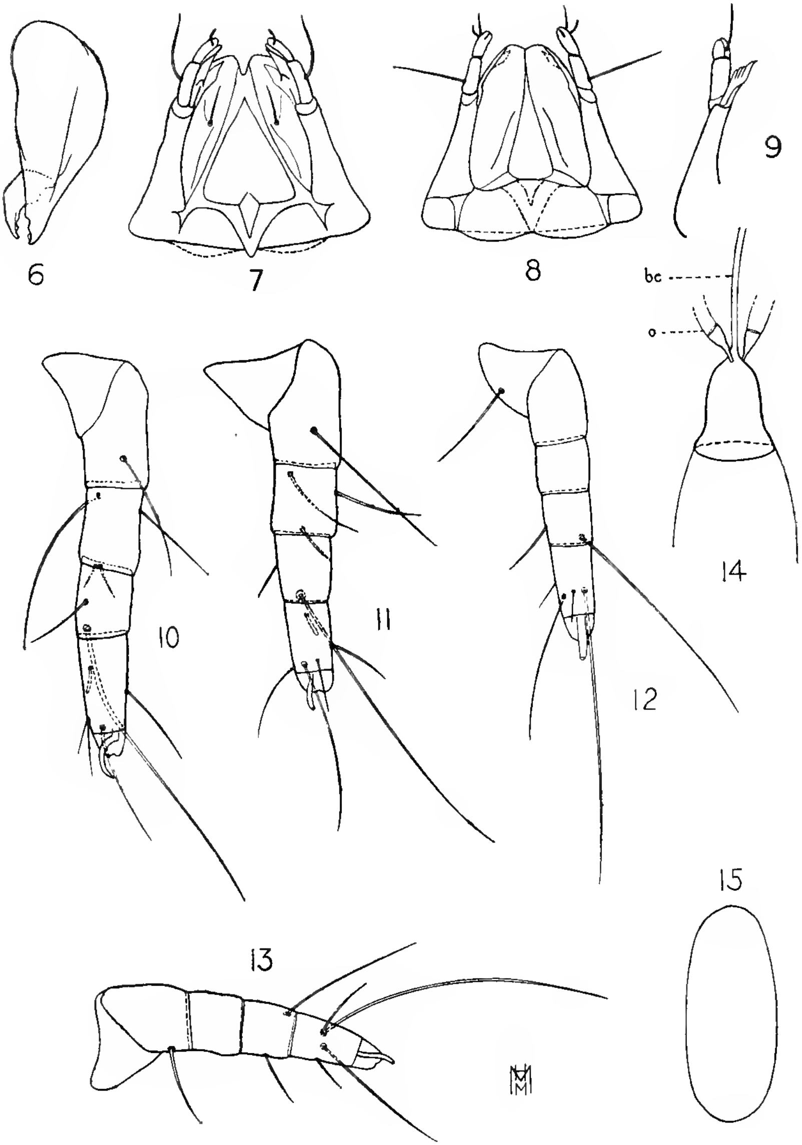
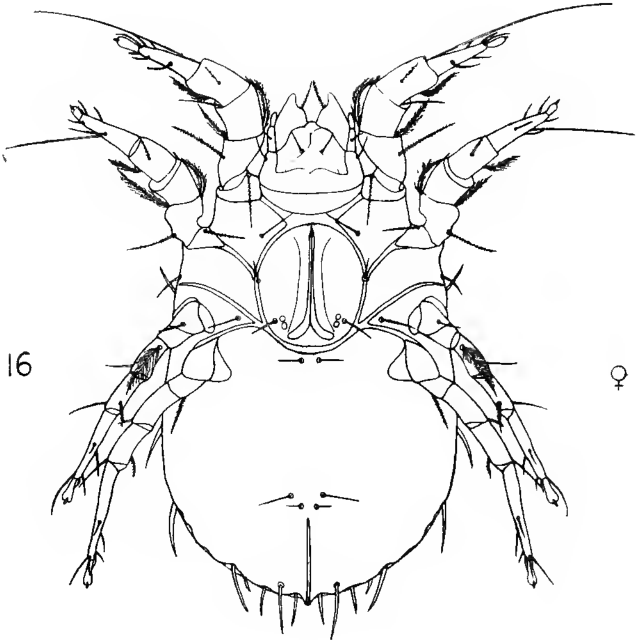


Histiogaster entomophagus.



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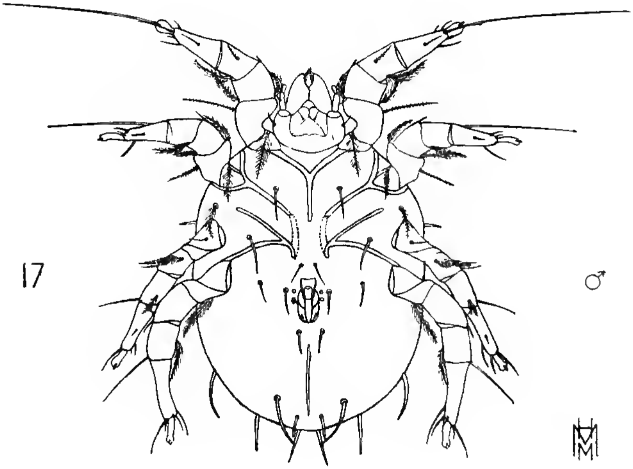

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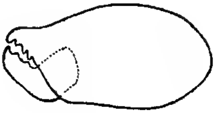
Glyciphagus fuscus.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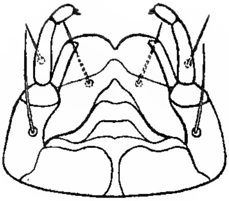
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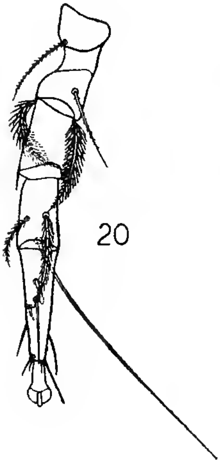
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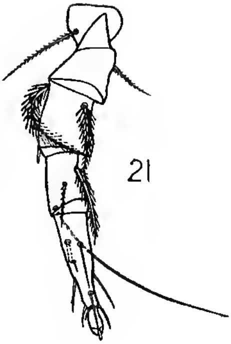
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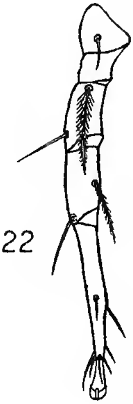
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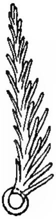
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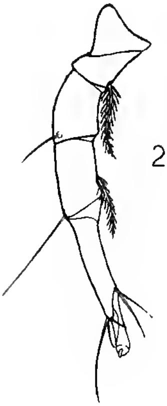
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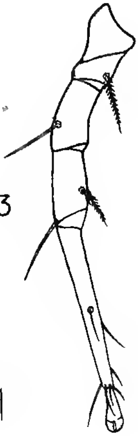
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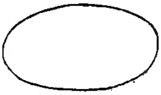
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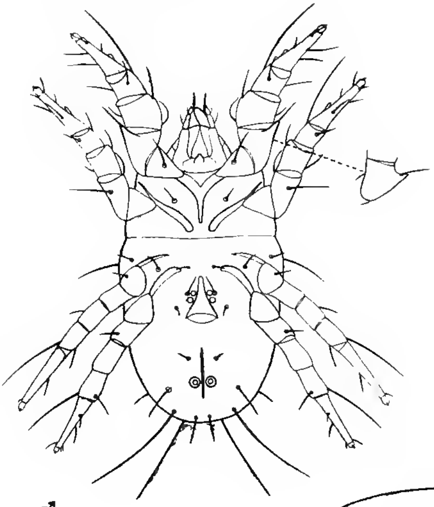
Glyciphagus fuscus.

PLATE VI.



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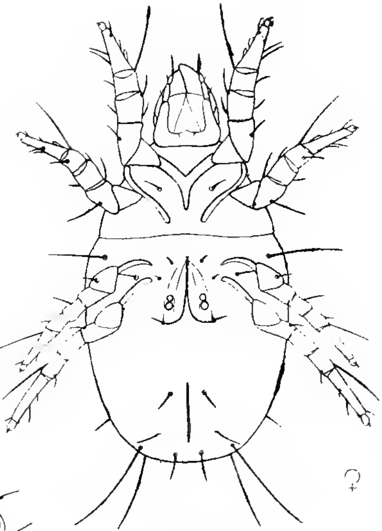

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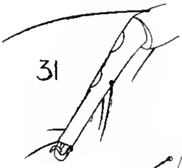

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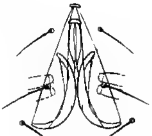

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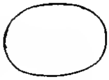

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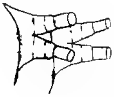

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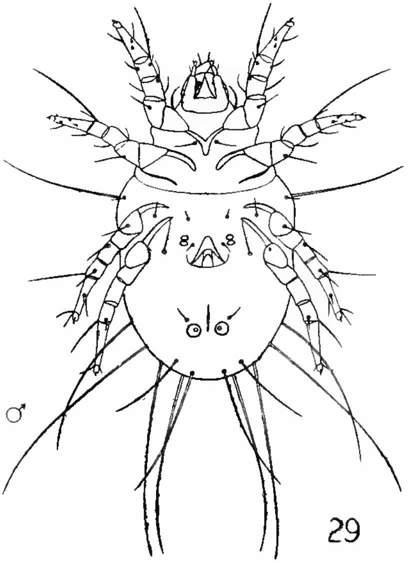

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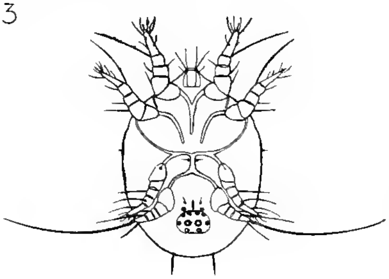

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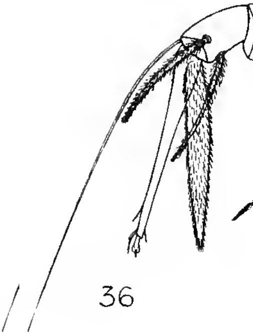
Aleurobius farinæ. Figs. 27, 28, 31–34. *Tyroglyphus longior.* Figs. 29, 30.



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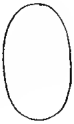

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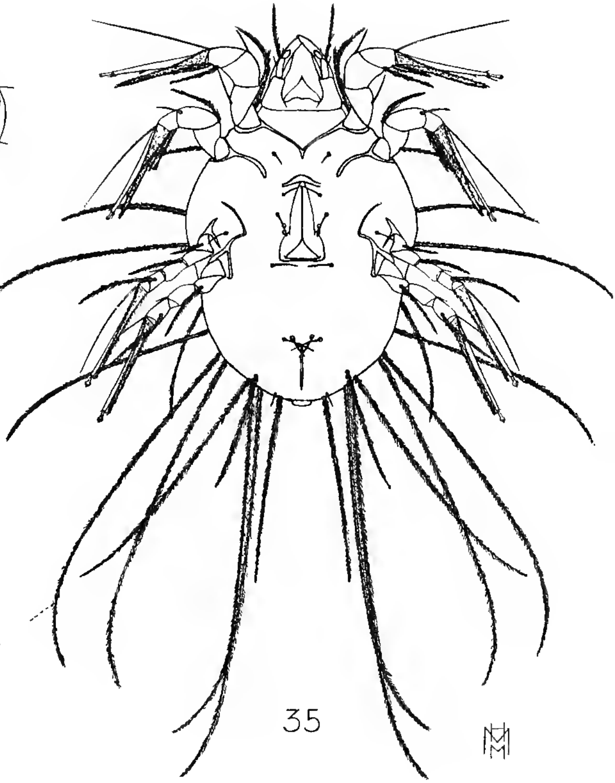

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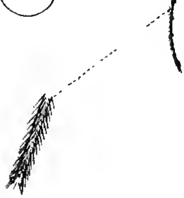
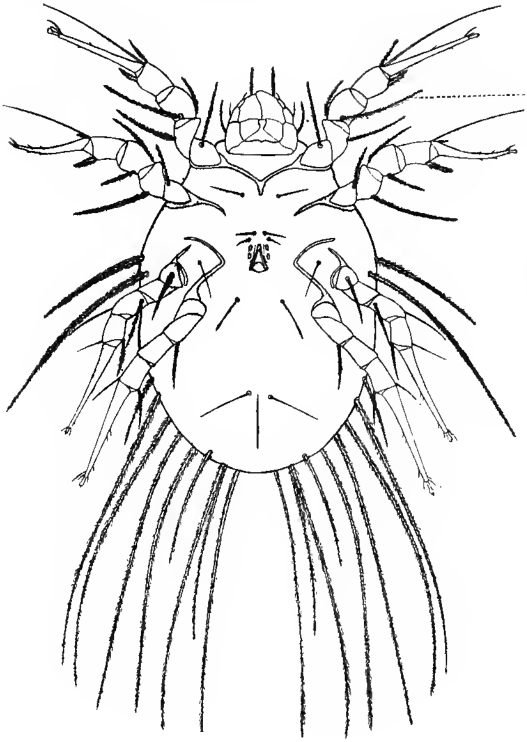


Glyciphagus cadaverum.



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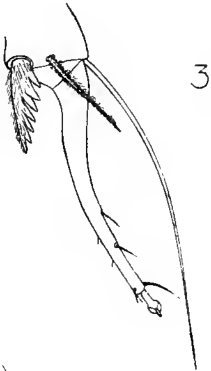

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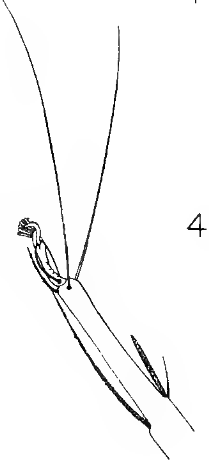

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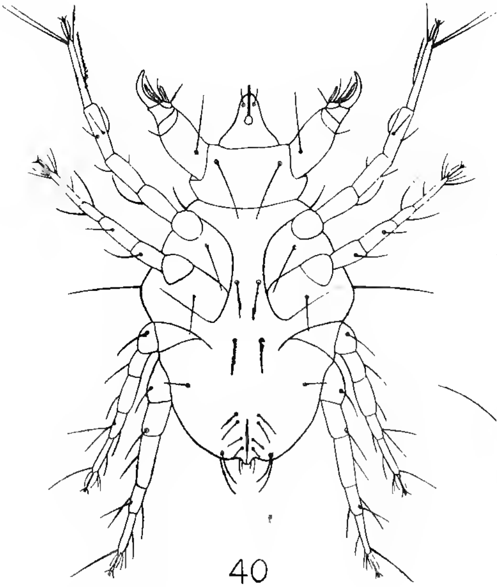

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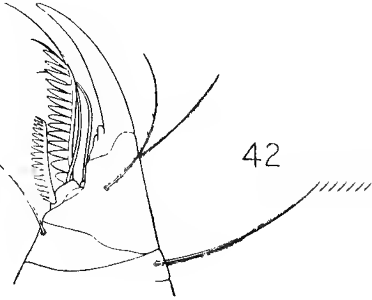

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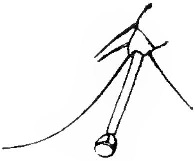
Glyciphagus ornatus. Figs. 3 -42.......



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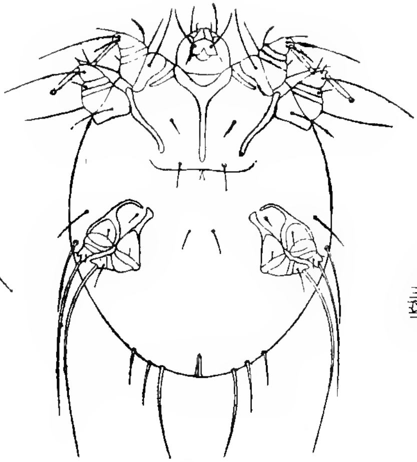

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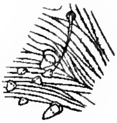

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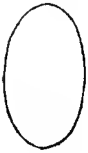

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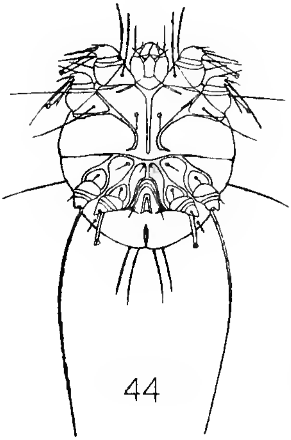

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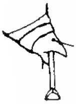
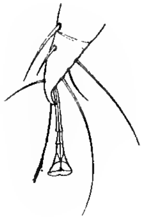


48

Sarcoptes scabiei, var. *equi*.



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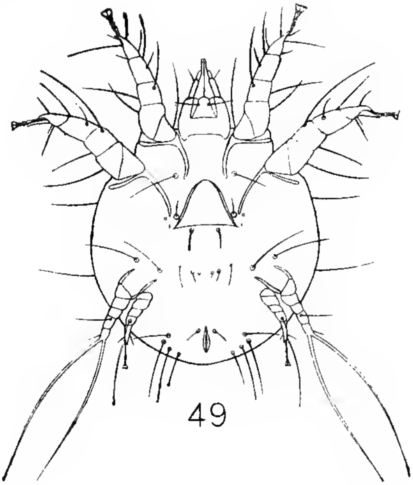

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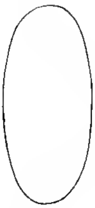

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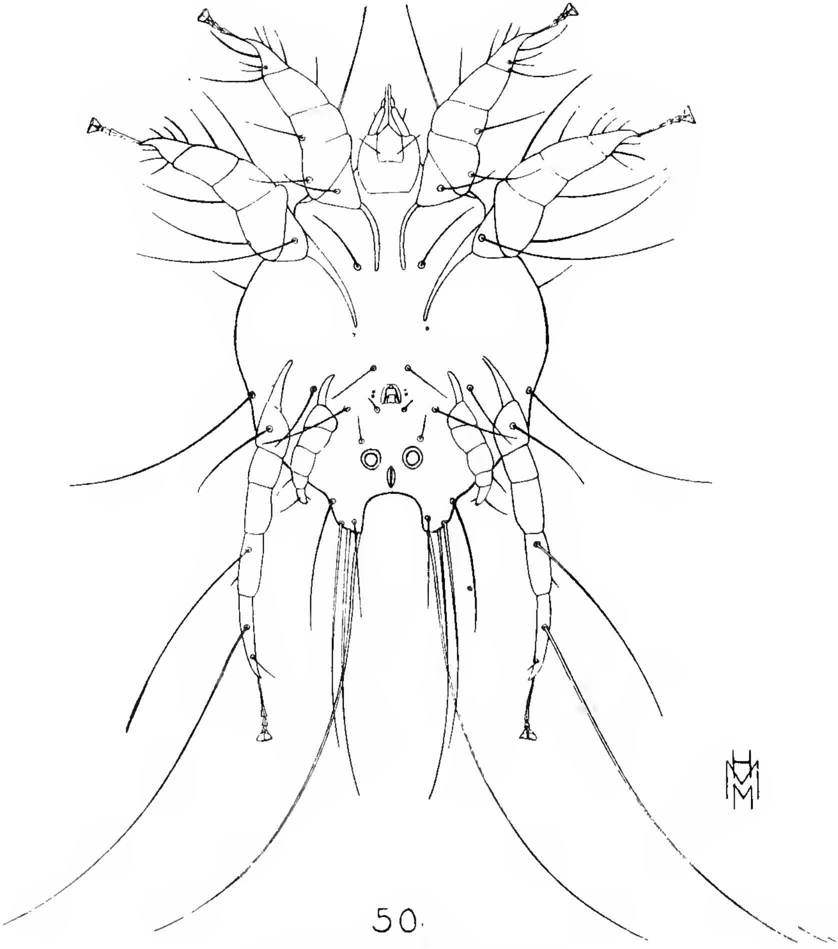

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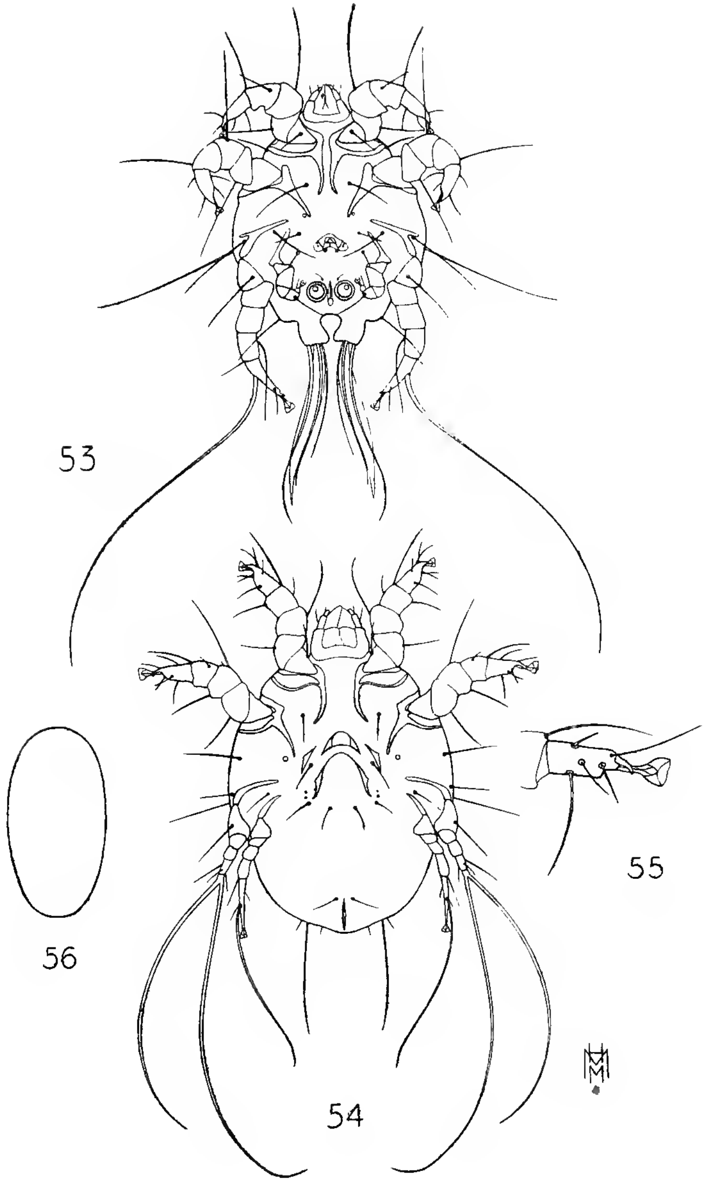
Psoroptes communis, var. *equi*.



Symbiotes (*Chorioptes*) *communis*, var. *equi*.

ROYAL SOCIETY.

REPORTS OF THE GRAIN PESTS (WAR) COMMITTEE.

No. 9.

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CONTENTS.

1. Editorial Note. By the Chairman of the Committee.

2. Note on the Hymenoptera parasitic on Beetles infesting Grain. By Prof. E. S. Goodrich, F.R.S.

3. Report on Parasitic Hymenoptera bred from Pests of Stored Grain. By James Waterston, M.A., D.Sc.

4. Insects associated with Grain, &c. By J. Hartley Durrant

EDITORIAL NOTE.

By the Chairman of the Committee.

At the last meeting of the Grain Pests Committee, held on October 21, 1920, it was resolved—(1) That the Final Report of the Committee (No. 10 of the present series) be approved for transmission to the Council of the Royal Society; and (2) That the articles in the present Report, No. 9, be approved by the Committee in their incomplete form, the Chairman being then authorized to receive the completed papers when ready and pass them for printing.

Report No. 10, giving a summary of the whole work of the Committee and the final recommendations, was published by the Royal Society in February, 1921, and it was at that time hoped that the present Report, No. 9, completing the series, would follow in a few weeks. Unexpected delays, caused partly by correspondence with America and partly by illness, have rendered it impossible to get the report ready for printing until this date; and even now one of the investigations proposed to and approved by the Committee, viz., Prof. Newstead's scheme for the examination of grain cargoes in co-operation with the Canadian authorities, is still unfinished.

Under these circumstances Prof. Newstead, who feels unable to do anything further in the matter, has authorized me to make the following statement on his behalf:—

As the result of correspondence with Canadian entomologists and conversations between Prof. Newstead and myself on the Acarid investigations carried on in the Liverpool laboratories, it became evident early in 1920 that there was a difference of opinion as to whether the Canadian grain brought to Liverpool became infected with mites (*a*) in the country from which it was exported, (*b*) on board ship during transit, or (*c*) during storage in this country.

The grain was found to be infected when it reached the port of Liverpool; the Canadian authorities, however, failed to find grain infected in their country. It was, therefore, suggested to our Committee that a joint investigation be arranged, and that certain cargoes should be sampled and reported on by the Canadian entomologists, and also by Prof. Newstead on arrival at Liverpool.

Early in November, 1920, Dr. F. J. Birchard (Department of Trade and Commerce, Dominion Grain Research Laboratory, Winnipeg), who had previously had a personal interview with Prof. Newstead and discussed the matter, wrote to say that he had taken up with the Canadian Government the question of the infestation with mites of Canadian grain, and the advisability of continuing the work on this side, and that it had been decided that the Canadian Entomological Branch of the Department of Agriculture should co-operate with the Liverpool laboratory, and continue the study as outlined in our Memorandum of October 20, 1920. A copy of the Memorandum referred to is as follows:—

I. Object of the investigation to locate the origin of Acarids in Canadian wheat.

II. Methods proposed to adopt are:—

A. *In Canada.*—The systematic examination of the large storage elevators, grain-cars, and vessels, and also cargoes of grain at time of loading, including the determination of moisture content and the presence or absence of mites.

B. *In England* (Liverpool).—The systematic examination of the cargoes of Canadian wheat which have been inspected by the Canadian authorities, with reference to the points named in A, on arrival in Liverpool. To determine how much moisture the wheat takes up under ordinary conditions of storage. To ascertain if mites subsequently develop in samples of wheat after storage in the laboratory.

III. Reports of the investigations to be submitted to the Dominion Government from time to time as may be thought desirable.

Prof. Newstead's severe illness during the last year has, however, absolutely prevented the joint work from being carried out. The investigation in Liverpool has, therefore, been discontinued, and the Canadian authorities have been notified that it is not now possible to carry out the proposed joint investigation, and that the solution of the problem must be left for future work and the results be published elsewhere.

W. A. HERDMAN.

LIVERPOOL,
November 1, 1921.

NOTE ON THE HYMENOPTERA PARASITIC ON BEETLES INFESTING GRAIN.

By EDWIN S. GOODRICH, F.R.S., Professor of Zoology and Comparative Anatomy in the University of Oxford.

This research was undertaken to ascertain how the presence of parasitic Hymenoptera may affect the various Coleoptera which commonly infest grain.

It is well known that several species of beetles infest wheat (*see* Barnes and Grove, " Memoirs of the Department of Agriculture in India, Chemical Series," Vol. IV, No. 6, 1916). Most of the samples I examined were kindly given to me by Prof. A. Dendy and Mr. J. Hartley Durrant, and contained *Rhizopertha dominica*, Fb., *Calandra oryzæ*, L., *Calandra granaria*, L., *Tribolium castaneum*, Hbst., *Læmophlœus*, sp., and *Silvanus surinamensis*, L.

Usually small parasitic Hymenoptera were also present, sometimes in large numbers. For obtaining the identification of these I have to thank Mr. Durrant. By far the most abundant of these parasites belong to the family Chalcidæ, the commonest being the slender *Chætospila elegans*, Wstwd., and the more bulky *Lariophagus distinguendus*, Först. Rarely a member of the family Proctotrypidæ occurred belonging to the genus Cephalonomia. Only Chætospila and Lariophagus are dealt with in this Report.

The first point to determine was which of the many beetles commonly present are attacked by the parasites, and at what stage in their life-history. It was soon found that Rhizopertha and the two species of Calandra are the victims. Moreover it is the larval stage or rarely the pupa which falls a prey. On opening infested wheat grains larvæ of these beetles are often found with a hymenopteron larva attached, usually on the dorsal surface of the abdomen, sometimes on the ventral surface. Occasionally two parasites are found on one larva. The reason why these species are alone attacked is probably because the larva being bulky and of sluggish habit, with a swollen body of soft succulent tissue covered only by a thin cuticle, are unable to defend themselves and afford ample nourishment for the parasite. The larva of Tribolium and Læmophlœus, on the other hand, are elongated active creatures protected by thick chitin. The laying of the parasitic egg has not been observed; but presumably the Chalcid deposits it through the hole originally made by the beetle larva when it penetrated the grain in which it undergoes its development. The parasite absorbs the contents of its host which gradually becomes reduced to a brown and shrivelled skin. The Chalcid then pupates and eventually emerges as a perfect insect from the grain. Every beetle larva attacked is irrevocably condemned to death; thus every adult Chalcid has accounted for one beetle. Since the Hymenoptera are sometimes very numerous they must seriously interfere with the multiplication of the beetles, and must therefore be reckoned as a useful factor in moderating their ravages. In some samples as many as 40 per cent. of the larvæ were parasitized. The Hymenoptera are all the more useful since they prey on the larvæ of just those beetles which are the most destructive; Rhizopertha and Calandra being those forms which attack and feed on uninjured wheat grains.

By experimental breeding I have proved that Lariophagus attacks *Rhizopertha dominica* and both *Calandra oryzæ* and *C. granaria.* The experiments with Chætospila were not quite so successful, and, although they establish that this Chalcid attacks both the species of Calandra, the evidence was not conclusive with regard to Rhizopertha.

The parasites develop quickly, their larval life being necessarily somewhat shorter than that of their hosts. It might, therefore, be thought that they would soon exterminate the beetles; but this never seems to happen, at least, in laboratory cultures. Rather is it the parasite that tends to die out, especially in small cultures. In fact, there is a heavy mortality among the parasites themselves. On opening infested grains a dead Chalcid imago is often found with the withered remains of the beetle larva on which it fed.

The next problem was to discover to what is due the premature death of so many of the Hymenoptera. An examination of the dead Chalcids revealed the fact that they had themselves fallen a prey to the parasitic acarid *Pediculoides ventricosus*, Newport. An excellent account of this species has recently been given by Brucker (Bull. Sc. de la France et Belgique, vol. 35, 1901). It is remarkable in that the female is viviparous, the hind region of her abdomen expanding into a large hollow sphere in which the young develop.

This voracious acarid has been recorded before as feeding on the larvæ of beetles, moths, and even bees, but, so far as I know, not on parasitic Hymenoptera. When the latter are absent the Pediculoides will feed on the larvæ of Calandra; but when Chalcids are present the acarids seem to attack them by preference. Strangely enough, while in the case of the weevils the larvæ or pupæ alone are attacked by Pediculoides, it is the late pupa or imago stages of the Hymenoptera which are parasitized and killed. In a grain of wheat are often found the shrivelled remains of the Calandra larva on which the hymenopteron larva has fed, the dead or dying Chalcid imago, and the Pediculoides attached to it.

Thus the whole series of events is permanently recorded in chitin, and the complete tragedy can be unfolded, even from unpromising material, by soaking it in a strong solution of potash.

A large number of experiments were undertaken to ascertain and measure accurately the effect of the Chalcids on the rate of increase of the beetles. For this purpose numerous sets of jars were incubated, containing a given weight of wheat and a given number of weevils. After a month or more the jars were infected with a given number of Chalcids. After suitable intervals the insect contents of both infected and uninfected jars were counted and compared. Unfortunately the results have not been satisfactory, owing to various difficulties. It was found that in such comparatively small cultures, containing only one species of beetle, neither the weevils nor their hymenopterous parasites seemed to flourish normally. The parasites, indeed, die out as a rule in a few months, or even weeks, or, at all events, survive only in very small numbers. On carefully examining the cultures, I found them infested with Pediculoides, and have no doubt that the ill-success of these experiments was due in great part, if not wholly, to their presence.

Since the wheat used had been previously thoroughly sterilized by heat, it is clear that the Pediculoides had been introduced with the adult insects, and since the adult female Pediculoides could hardly have escaped notice and is not found on the adult beetles, the acarids must presumably have been transferred with them when quite young and small. At all events the adult weevil can act as the carrier of the Pediculoides.

Now it is obvious that in time both the Hymenoptera and the weevils would be exterminated by Pediculoides. But we know that in the mixed culture of ordinary infected wheat the weevils flourish, and the parasitic Hymenoptera continue to appear in large numbers for an indefinitely long time. In fact, a balance is established It would appear then that some factor keeps down the number of Pediculoides—some factor less effective in the small pure cultures than in the large mixed ones.

Pediculoides, however, is probably not the only enemy the hymenopteron parasites have to contend with. Recently I have had under observation cultures of wheat, infested with Calandra and Rhizopertha, in which appear considerable numbers of the Chalcid Lariophagus. On opening grains dead Chalcid imagines are sometimes found, but so far no Pediculoides. Possibly some other acarid here attacks the Hymenoptera ; but if so it has not yet been identified.

In conclusion it may be stated that several species of Hymenoptera attack and eventually kill the larva of *Calandra oryzæ*, *C. granaria*, and *Rhizopertha dominica*; that these parasites considerably reduce the number of beetles infesting grain, but do not succeed in exterminating them because they themselves fall a prey to carnivorous acarids. Although the Hymenoptera may well be considered as valuable allies in the fight against weevils, yet the results of this research do not justify the hope that they could be successfully used in practice to get rid of the grain pests.

October 19, 1920.

REPORT ON PARASITIC HYMENOPTERA, BRED FROM PESTS OF STORED GRAIN.

By JAMES WATERSTON, M.A., D.Sc. (Assistant in Department of Entomology, British Museum, Nat. Hist.).

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The working out of the large collection of parasitic *Hymenoptera*, formed by Mr. J. Hartley Durrant and his colleagues in the course of the present enquiry into the pests of stored grain, has been so frequently and so seriously delayed, that I think it not irrelevant to mention some of the handicaps under which the task was attempted. And I do so the more readily as it gives me an opportunity of thanking heartily those friends whose help has materially contributed to lighten the labour.

It was in the spring of 1917 that Mr. Durrant asked me to identify some *Calandra* parasites in connection with the present Report. One of the species then submitted was the *Rhabdepyris* diagnosed below, and as I had recently, with Mr. R. E. Turner, paid some attention to the Bethylidæ, our collaboration was continued in the description of this new species. In June of the same year, while waiting for orders to go to France, I was, on short notice, sent to Salonika, and for eight months nothing was done to the collection of parasites, which meantime grew in numbers steadily. So large indeed did it ultimately become that when in London for a short time in the spring of 1918, I could see no prospect of dealing with the material and reluctantly gave up the idea of completing the work. Fortunately at this juncture the services of Dr. Luigi Masi (Museo Civico di Storia Naturale, Genoa) were available, and having been granted special facilities for visiting Genoa when returning to Salonika, I was able to place in my friend's hands a complete set of the unworked parasitic material. A duplicate set, complete as far as possible, was meanwhile left at S. Kensington. From Genoa I proceeded to Rome, and while there consulted with Mr. A. E. J. Terzi, whose drawings so admirably illustrate this Report. For a considerable time after demobilization, I had no occasion to refer to the collection of parasites retained at S. Kensington. Latterly, as the result of intermittent work, the material was analysed and determined.

Meanwhile Dr. Masi, after finishing his identifications of the material left at Genoa, found himself unable to carry out his original intention of writing a Report, and returned the specimens with some valuable notes. Our results have tallied closely, and if the Report, which it has fallen to me to draw up, has suffered in one way from a vexatious delay, it has gained in another by the double scrutiny of the greater part of the material which has resulted.

But, besides suffering from the interruptions referred to, the study of these parasites has presented many difficulties. The material to begin with was found to be in poor condition. Much of it was separated after death from wheat, etc., and the rubbing to which specimens had been subjected had frequently resulted in the loss of appendages. In the Pteromalids the wing-fringe was almost invariably nearly wanting. It is apparently an exceedingly fugacious structure, and it has not been shown in all the drawings. While it might have been possible to obtain bred specimens from another source from which to complete the fringe, it has seemed on the whole better to illustrate the Report from material actually collected. One advantage of this is that the wings are here represented as they are most likely to be seen by other workers.

It might have been supposed that the identification of such a series of parasites, as from the nature of the hosts must be largely cosmopolitan, would be easily arrived at. The very opposite has proved to be the case. The majority were found to be Chalcids, of which there are still few students. The literature was scattered, descriptions inadequate and scantily illustrated. It became evident too, that an extensive, if presently irreducible, synonymy must exist for many of the species. In the circumstances it has seemed best (*a*) for the most part not to attempt to offer a complete synonymy but to employ in each case the oldest name of which one could be reasonably certain, even when one suspected that another might have priority, and (*b*) to give such figures and notes on all the species as would enable them, with ordinary care, to be recognized by future workers.

In this connection it is a pleasure to acknowledge both on Dr. Masi's account and on my own the help so readily rendered by members of the staff of the Entomological Bureau of the Division of Agriculture, Washington—more particularly by Messrs. J. C. Crawford and A. B. Gahan, who have compared, confirmed, or determined samples of our material. An earlier correspondence with Mr. A. A. Girault on some parasities of *Calandra* from Nyasaland has also proved of use in the present connection.

Of Mr. Terzi's drawings one need only say that they have been executed with his customary skill and attention to detail. They are exact copies of the parts represented, and nowhere schematic, while special pains have been taken to render the chætotaxy correctly.

The notes on the species are based on a study of whole insects examined under a Zeiss binocular with objectives a_2 and a_3 and eyepieces 3–5. More minute details have been made out from dissections (wings, trophi, antennæ, legs, etc.) mounted in balsam and studied with objectives up to $\frac{1}{6}$, and eyepieces I–V (Zeiss) in an ordinary compound microscope.

The Bibliography given refers with one or two exceptions, only to Pteromalid parasites of Coleopterous grain pests.

Before dealing in detail with the insects determined during the present enquiry it may be useful to give a systematic note of their names together with those parasitic hymenoptera reported by other investigators from stored grain, flour, etc. The following list, compiled from many sources, is believed to be fairly complete:—

HYMENOPTERA.

Ichneumonoidea.

BRACONIDÆ.

- HABROBRACON Ashm.
  - brevicornis Wesm.
  - hebetor Say.
- CHREMYLUS Hal.
  - rubiginosus Nees.
- APANTELES Först.
  - ephestiæ Baker.
  - ensiger Say = *carpatus* Say ♀.
- METEORUS Hal.
  - ictericus Nees.

OPHIONIDÆ.

- NEMERITIS Hal.
  - canescens Grav = *oahuensis* Ashm = *ephestiæ* Cam.
- CAMPOPLEX Grav.
  - frumentarius Rnd.
- LIMNERIA Holmgr.
  - ephestiæ Ashm.
- POLYCLISTUS Först.
  - mansuetor Grav.

Chalcidoidea.

PTEROMALIDÆ.

- BRUCHOBIUS Ashm.
  - laticeps Ashm.
- LARIOPHAGUS Crawf.
  - distinguendus Först.
  - puncticollis Möll.
  - utibilis Tuck.
- APLASTOMORPHA Crawf.
  - vandinei Tuck = *pratti* Crawf.
- MERAPORUS Wlk.
  - requisitus Tuck.
- PTEROMALUS Swed.
  - calandræ How.
  - oryzæ Cam.
  - oryzinus Rnd.
  - tritici Gour.

SPALANGIIDÆ.

- SPALANGIA Latr.
  - rugosicollis Ashm.
- CHÆTOSPILA Westw.
  - elegans Westw.

Vespoidea.

BETHYLIDÆ.

- RHABDEPYRIS Kieff.
  - zeæ Turn. and Waterst. *sp. nov.*
- CEPHALONOMIA Westw.
  - *Spp ?*

Besides the species listed above, the following names have appeared among the reputed parasites of grain pests, *viz.*, *Meraporus graminicola* Wlk., *Cerocephala cornigera* Westw., *Sciatheras trichotus* Ratz., *Theocolax formiciformis* Westw. I am satisfied that all these records are erroneous, and have discussed the evidence offered in support of each elsewhere and given my reasons for rejecting them. Of the Braconidæ listed *Habrobracon brevicornis* Wesm. has already been recorded by Mr. Durrant as a parasite of *Ephestia elutella* Hübner (**19**, p. 616), and (**21**, pp. 2 & 18). Mr. Durrant has also noted the occurrence of the Ichneumonid *Nemeritis canescens* (**20**, lvii & **21**, pp. 2 & 19), *cf.*, Morley (**42**, p. 134) and Krüger (**38**, p. 58). Neither species need here be further noticed.

The bulk of the collection examined, several hundred specimens, belonged to the families Pteromalidæ and Bethylidæ. In determining this material it has been necessary to review as far as possible the records available of species within these families bred from stored grain, etc.

The results may be grouped under three heads:—

A.—Records which on examination were found to be erroneous.

B.—Records of species which were either unrecognizable or if recognizable were not represented in our material.

C.—Species actually determined.

Under A and B the successive references to the name under discussion have been analysed and estimated. It is probable of course that under B some synonyms of names in C have unavoidably been left standing.

A.—*Erroneous records.*—As I have noted above, four names fall within this category. Apart altogether from the value of the records discussed under each, I think it unlikely that the insects to which they respectively apply are parasites of grain pests. The suggestive name of one, *Meraporus graminicola,* refers only to the trivial fact that the insect is commonly swept from grass. Kurdjumov noted (**39**, p. 7) that none of the American species placed up to 1913 in *Meraporus* really belonged to that genus. So far as I know no parasite of grain pests is a true *Meraporus.*

Meraporus graminicola.

Curtis (**15**, p. 322) records the rearing of a single specimen of *M. graminicola,* or a closely allied species, from grain. His example was "too mutilated to draw from." This remark is important, as it proves that the figures of *M. graminicola* (Plate K, fig. 19 and h.), were not done from the actual ♀ reared but from a specimen of *M. graminicola* "which we often find in this country in July." The source of the sample of the grain from which Curtis bred his example is uncertain. The context shows it may have been Ancona or the East Indies. Curtis's determination seems to me unreliable and the doubt with which he qualifies it to be only too well founded. Yet Fitch (**25**, p. 48), discarding the original qualification, says that Curtis bred an apterous ♀

of *M. graminicola* from these weevils. It is on this slender basis of misstatement and probably of misidentification that the alleged parasitism of *Meraporus* on *Calandra* rests. As to what insect Curtis really had before him, I have little doubt it was the *Lariophagus* here recorded as *L. distinguendus* Först (*cf.*, Kurdjumov, **39**, p. 15).

Cerocephala cornigera.

The reputed parasitism of this species on *Calandra* is, in my opinion, quite baseless, as an examination of the records shows. Elliott and Morley (**43**, p. 487) say definitely that Reinhard (**46**, p. 75) reported *C. cornigera* from *Calandra*, but referring to the passage quoted we find Reinhard stating merely that he had received *another species* (*i.e.*, not *C. cornigera*) belonging to the same genus (*i.e.*, *Cerocephala*) from Reichenbach, taken at Dresden and found dead amongst several examples of *Calandra granaria* in millet. The grain came from India originally, and as it had been stored some time in Dresden, Reinhard was unable to say whether the beetle had been parasitized there or in India. The other records are equally unsatisfactory. Dalla Torre (**16**, p. 206) in a footnote to *C. cornigera* gives *Sitophilus granaria* and *Hylesinus fraxini* as hosts. Thompson (**54**, p. 212) says, if I understand him rightly, that *C. cornigera* occurs in houses and may live parasitically on *Calandra*. Vassiliev's reference (**58**, p. 22) is obviously second-hand.

Making allowance, then, for misquotation, mistranslation, and conjecture, it is evident that Reinhard's Dresden record alone needs to be taken seriously, and it, we can hardly doubt, refers to *Chætospila elegans*.

Cerocephala (Sciatheras) trichotus Ratz.

This species, which has, I believe, no connection with wheat pests of any kind, has been recorded in error from Calandra by Fitch (**26**, p. 21), *q.v.*, under *Theocolax formiciformis*. I think with Reinhard (**46**, pp. 75–76), Masi (**40**, p. 188), and others, that the genera *Sciatheras* Ratz. and *Cerocephala* Westw. are absolutely synonymous. Masi (**40**, p. 188) thinks that there are possibly two species in the genus, viz., *C. cornigera* Westw. and *C. trichotus* Ratz. Reinhard treats *C. trichotus* as a synonym, and rightly in my opinion, as such differences as one can note in the description are probably sexual. Ratzeburg (**45**, p. 209) knew only the ♀. It should be noted that:—

Cerocephala cornigera parasitizes *Hylesinus*.
Theocolax formiciformis parasitizes *Anobium*.
Chætospila elegans parasitizes *Calandra*.

The three genera, though valid and abundantly distinct, have been needlessly confused. The best treatment of the systematics of this group of genera is that of Masi (**40**, p. 188–189).

Theocolax formiciformis Westw.

Fitch (**25**, p. 47) records from Calandra about a dozen *Cerocephala formiciformis* Westw., or a very closely allied species. Later (**26**, p. 21) he recognizes the erroneousness of this record after obtaining the true

C. formiciformis from *Anobium*. He therefore quite correctly assigns his material to *Chætospila elegans* Westw., but somewhat incomprehensibly proceeds to sink Westwood's genus and species as synonyms of *Sciatheras trichotus* Ratz.

B.—The following records refer either to names which ultimately will fall as synonyms or, if valid, refer to species not represented in the material which I have studied.

Pteromalus tritici.

Goureau (**33**, p. 341) says "Le Charançon du blé (*i.e.*, *Calandra granaria*) a un ennemi naturel qui en détruit un grand nombre et qui en débarrasse quelquefois les greniers pour plusieurs années." The description of *P. tritici* which follows does not enable me to recognize the species, but the author's concluding remarks, "Il est quelquefois si nombreux que les tas de blé et les sacs qui en renferment en paraissent verts," suggest *Lariophagus distinguendus*. Vassiliev (**58**, p. 22) lists *P. tritici* Gour. as a reputed parasite of *Calandra granaria*, and Kurdjumov regards it as a synonym of *L. distinguendus* Först. Rondani (**49**, p. 195) leads us to infer that he was acquainted with *P. tritici*, as he distinguishes it from *P. oryzinus* by the colour of the antennal scape.

Pteromalus oryzæ.

Described by Cameron (**8**, p. 184, Plate I, figs. 2 and 2^{a}) as "a parasite of the destructive rice weevil, *Calandra oryzæ*." This description is noted by Cotes (**12**, No. 1, p. 24, 1893), who later (**12**, No. 6, p. 11, 1896) gives a figure of the whole insect from one of Cameron's types, adding that the type material had been taken by himself in Calcutta in February, 1888, in close association with the weevil *C. oryzæ* L.

Cotes has two further notes on the species. In his preliminary account of the wheat and rice weevil (**10**, pp. 4–5), when noticing *Pteromalus calandræ* Hw., he remarks that this appears to be distinct from the one he "found in January, 1888, creeping on a sample of weevily wheat in Calcutta." In his Conspectus of insects affecting crops in India (**11**, p. 155) he speaks of *Pteromalus oryzæ* Cam., "a minute coppery green-coloured insect believed to be parasitic on the wheat and rice weevil (*Calandra oryzæ*)."

Barlow (**3**, p. 219) also lists the species.

None of the above references enable one to identify *Pteromalus oryzæ* with certainty. But it plainly cannot be a *Lariophagus*, and the choice lies between *Bruchobius* and *Aplastomorpha*. In the latter case Cameron's name would probably displace *vandinei* Tucker.

Pteromalus oryzinus.

Rondani (**48**, pp. 130–131) first mentions this name without description as a new species bred from *Sitophilus oryzæ*, the parasite being "affine a quello che uchido le larve del *Sitophilus granarius*." Later (**49**, p. 195) he diagnoses *P. oryzinus* and adds "ex seminibus ortus oryzæ, in quibus larvæ plures vivebant *Calandræ oryzæ* Lin. (obs. Celi.)."

Subsequent notes by the same author add nothing to this, and I am unable to judge to what particular enemy of *Calandra oryzæ* these remarks and description apply.

Pteromalus calandræ

is discussed in C under *Lariophagus distinguendus*.

Meraporus requisitus.

Of this species described by Tucker (**55**, p. 344) only the ♂ is known. The unique type was reared with *A. vandinei* from rice, primarily infested by *Calandra oryzæ*, obtained by Van Dine in a rice mill at Welsh, La., 2.8.1909.

I am unacquainted with any subsequent records of this species.

C.—Including *Habrobracon brevicornis* and *Nemeritis canescens* already referred to, eleven species of parasitic *Hymenoptera* are represented in Mr. Durrant's material. Of these six are Chalcids belonging to the families Pteromalidæ (5) and Spalangiidæ (1), while three are Bethylidæ, one here referred to the genus *Rhabdepyris* Kieff, and the others to *Cephalonomia*. The *Cephalonomia* species are not dealt with in this paper but will form the subject of a subsequent note.

N.B.—"*Vide infra*" refers to Mr. Durrant's detailed records in Part IV of this number.

Chalcidoidea.

PTEROMALIDÆ.

The following key will facilitate recognition of Pteromalids bred from *Bruchus*, *Calandra*, and *Sitodrepa* affecting grain.

1. Head, large and broad; pedicel distinctly shorter (Fig. 1 (a) (d)) than first normal funicular joint, *marginal* (Fig. 1 (b)) *and radial veins subequal.* Propodeon (Fig. 2) with "long neck" and no median keel. . . . . *Bruchobius laticeps* Ashm.

Head neither unusually large nor broad, *marginal vein distinctly longer* (Figs. 3, 8, 11) *than the radius.* . . . . (2)

2. Propodeon (Fig. 4) short, abruptly declivous and shining posteriorly, duller dorsally, without any "neck," its stigma practically touching the lateral fold [which is indicated only basally (anteriorly)] and standing at the top of a broad sulcus between which and the midline the surface is somewhat swollen. . *Aplastomorpha vandinei* Tuck.

Propodeon (Figs. 7, 10, 12) more elongate, with distinct "neck," lateral folds well developed to beyond the stigma posteriorly and remote from the latter. . . . . (3)

3. First normal funicular joint (Fig. 11 (a)) quadrate, lateral folds

(Fig. 12) of propodeon completely indicated but not surmounted by definite ridges. Surface between the folds only reticulate or punctate, posterolateral angles rounded. . . . . . *Lariophagus utibilis* Tucker.
First funicular joint (Fig. 6) cylindrical, posterolateral angles distinct and acute. . . . . (4)

4. Larger species, setigerous punctures of scutum (Fig. 9) well marked and numerous ; marginal vein (Fig. 8 (*b*)) densely set with short bristles, mid-area (Fig. 10) of propodeon immediately behind metanotum divided into a number of quadrate cells. . . *Lariophagus puncticollis* Möll.
Smaller, marginal vein (Fig. 8 (*c*)) with fewer bristles, propodeon with incomplete ridges basally, subparallel (Fig. 7) with posterior edge of metanotum. . . . . *Lariophagus distinguendus* Först.

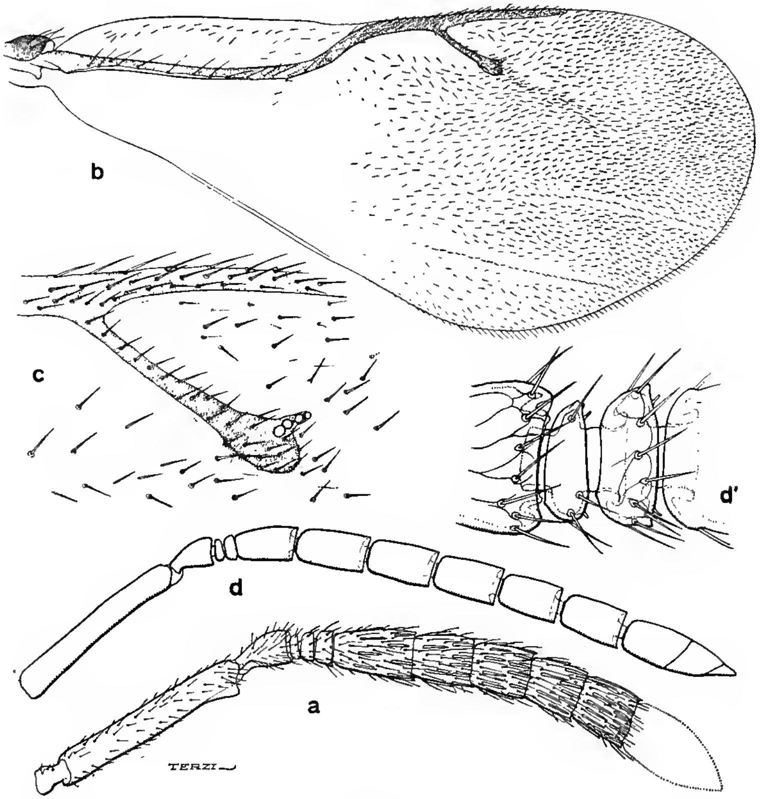

Fig. 1.

Bruchobius laticeps, ♀, (a) antenna, (b) wing, (c) radius : ♂, (d) antenna, (d') ring joints.

BRUCHOBIUS Ashm.

Bruchobius, g. nov., Ashmead (W. H.). Mem. Carn. Mus., Vol. I, No. 4, p. 314, I, 1904. Genotype *Bruchobius laticeps* Ashm., *loc. cit.*

Bruchobius laticeps Ashm.

Redescribed by Crawford (**14,** p. 250) who diagnoses both sexes. Ashmead's original diagnosis of *B. laticeps* occurs in a dichotomic table in which the characters of the genus are not separated from those of the genotype, though such a representative species is indicated. No host is mentioned. Crawford's later notes were based on Ashmead's type material, which was bred from *Bruchus quadrimaculatus*, Washington, D.C., 12.11.1896, F. C. Pratt Coll. Girault (**32,** p. 130) finds *B. laticeps* associated with cow-pea weevils in Texas.

Colour notes.— ♀ Head, thorax, and coxæ, dark green, at most with submetallic aeneous or dark blue reflections. Eyes, dark chocolate, pubescence paler. Abdomen, smooth, shining, immaculate, metallic with aeneous or purplish reflections. Antennæ, scape, clear yellowish-brown (light honey colour), pedicel, like scape but darker above. Funicle, in some brownish-black, in others hardly darker than the scape but with sutures between the joints distinctly darker. Legs: tarsi, pale whitish; fore tibiæ, brown, narrowly paler at base; mid and hind tibiæ, distinctly pale at base, then brown to about two-thirds and broadly pale apically; femora, brown, darker superiorly in some specimens, especially on the hind legs. Wings, hyaline. Veins, blackish-brown. ♂ similar to ♀ but with slightly paler neuration and antennæ. A large pale whitish spot on basal half of the abdomen.

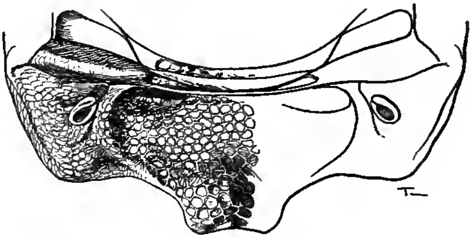

Fig. 2.

Bruchobius laticeps, ♀, propodeon.

This species is distinguished in both sexes by propodeal characters. The ♀ has three (Fig. 1 (a)) ring joints. The left mandible has three teeth, of which the uppermost is broad and straight edged.

APLASTOMORPHA Crawf.

Aplastomorpha, new genus, Crawford (J. C.). Proc. U.S. Nat. Mus., No. 1979, Vol. 45, p. 252, 22.5.1913. Genotype *A. pratti* Crawf. ♀, ♂, *loc. cit.*

Aplastomorpha vandinei Tucker.

Meraporus vandinei Tucker (E. S.). Can. Ent. XLII, No. 10, p. 343, ♀ ♂, October, 1910.

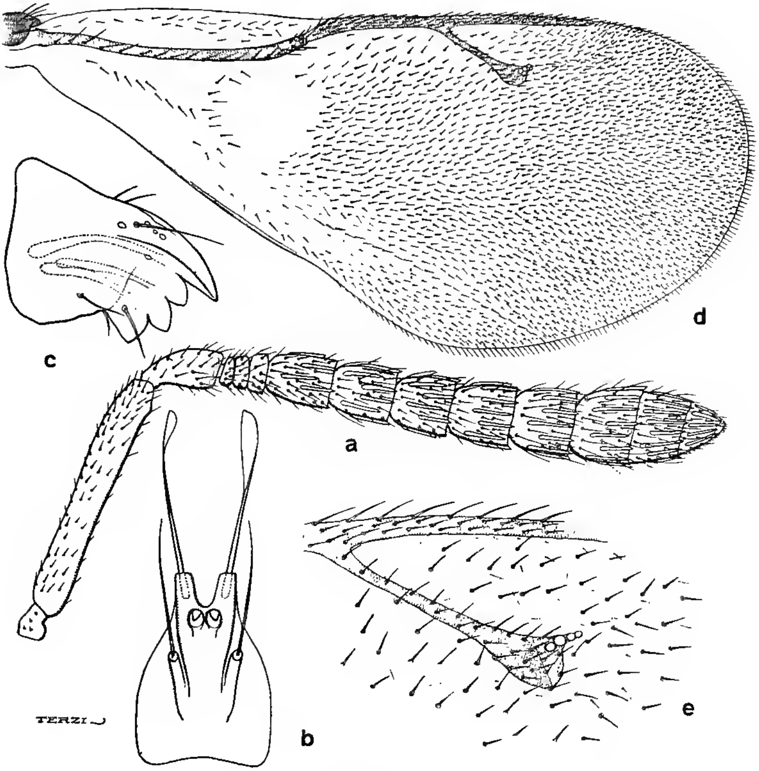

Fig. 3.

Aplastomorpha vandinei, ♀ (a) antenna, (b) labrum, (c) right mandible, (d) wing, (e) radius.

Aplastomorpha pratti Crawf., *loc. cit.*

Meraporus vandinei was originally procured from seed wheat infested by *Calandra oryzæ* L. at Plano, Texas, 26.7.1909. The parasites emerged 11.9.1909. *Aplastomorpha pratti*, which appears to be a synonym of

M. vandinei, was described by Crawford from Dallas, Texas, without indication of the host of the type specimen. Crawford adds that Ashmead (whose MS. name he adopted for this new species) bred his original specimens from *Bruchus quadrimaculatus*, collected at Washington, D.C. Crawford's description, however, is based on other material. Bodkin (**4**, p. 9) records *A. pratti* as a parasite of *Lasioderma serricorne* F. in British Guiana, while Runner (**50**, p. 35) says its larvæ attack larvæ and pupæ of the tobacco beetle (*i.e.*, *L. serricorne* F.).

Neocatolaccus australiensis Gir. (**30**, p. 306), subsequently (**31**, p. 313) placed by its author in the genus *Aplastomorpha*, has been reported from several localities in Queensland, 1911–1914. It has been taken (*a*) on windows, bred from miscellaneous forest galls, reared from the "grain moth" (Girault, **30**, p. 306); also (*b*) swept from tea-tree foliage; abundant in seed corn infested by *Calandra granaria* (Girault, **31**, pp. 313–314); and (*c*) reared with *Spalangiomorpha fasciatipennis* Gir. (det. doubtless by the author) from weevil-infested grain (G. F. Hill, **35**, p. 16).

Some of these records probably refer to *A. vandinei*, but without examining the type I should not care to sink *Neocatolaccus australiensis* Gir. as a synonym of Tucker's species. [For definite record of *A. vandinei* in company with *C. elegans* in Australia, *see below.*]

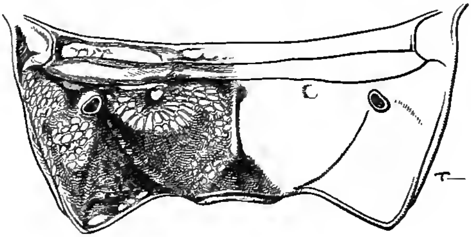

Fig. 4.

Aplastomorpha vandinei, ♀, propodeon.

Colour notes.—♀ Dark green, submetallic; antennal scape clear brownish-yellow; pedicel and funicle generally much darker but variable, sometimes pale with the joints infuscated; wings hyaline; veins brown; coxæ like thorax; femora (except narrowly and indistinctly at base and apex) and fifth tarsal segment blackish-brown; legs otherwise pale, the tibiæ, even if slightly infuscated, markedly lighter in tone than the femora. ♂ differs from the ♀ chiefly in the generally darker coloration especially of the tibiæ, which as a rule are concolorous with the femora, the knees being thus conspicuously pale. A large pale spot extends from the posterior two-thirds of the first tergite well on to the third.

This species may be recognized at once by the peculiar propodeon.

The mandibles are strongly 4-dentate (Fig. 3 (c)). In the ♀ there are three (Fig. 3 (a)) ring joints.

LARIOPHAGUS Crawf.

Lariophagus Crawford (J. C.). Proc. Ent. Soc. Wash., XI, p. 52, 1909. Genotype *Lariophagus texanus* Crawf., *loc. cit.*

To this genus the following three forms (which appear to be separable though closely related, and plainly congeneric wherever they may ultimately be placed) have been referred mainly on the authority of Kurdjumov, who, having made a special study of the genotypes of the *Pteromalidæ*, has assigned *Pteromalus distinguendus* to *Lariophagus* (**39**, p. 15).

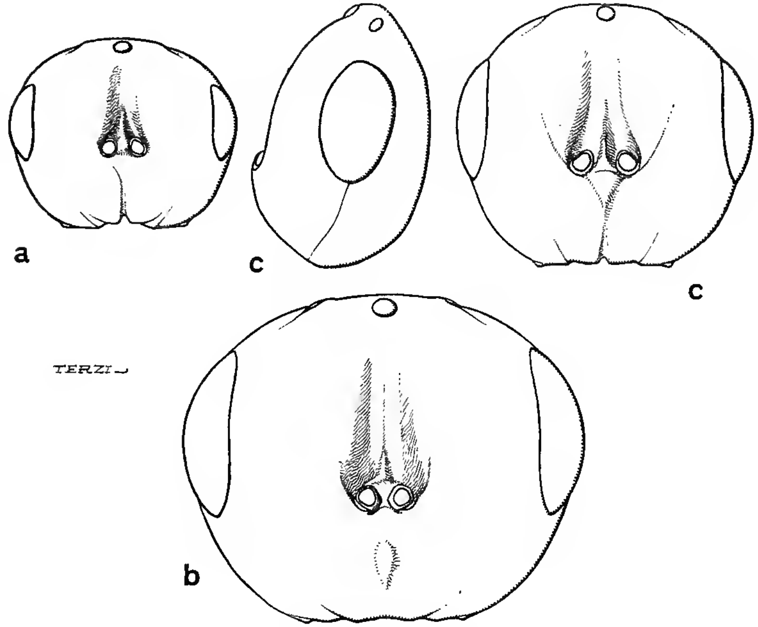

Fig. 5.

Heads, ♀, of (a) *Lariophagus utibilis*, (b) *Aplastomorpha vandinei*, (c) *Lariophagus distinguendus*, front and profile.

Lariophagus distinguendus Först.

Pteromalus distinguendus Förster (A.). Beitr. Mon. Pteromal, p. 17, Aachen, 1841.

This species was originally described without any reference being made to its host, but it is possible that Förster was not ignorant of this as he seems to have taken the species in numbers. The British Museum Collection possesses several examples of both sexes determined and labelled by Förster himself. These specimens are conspecific, one pair, presented by E. Doubleday so far back as 1846, bears the locality "Aix la Chapelle." Another pair, from F. Smith's Collection, is labelled simply "Prussia." The records given below rest on a direct comparison with the pair received in 1846, which are probably to be regarded as co-types of the species.

The earliest published reference, with which I am acquainted, to the parasitism of *Lariophagus distinguendus* on *Calandra* is an important note by Kurdjumov (**39**, p. 15), which deserves to be quoted in full. "Note.—In k. k. Naturhist. Hofmuseum, Vienna, there are many specimens of this species labelled 'from *Sitophilus granaria*, 1879.' John Curtis mentions *Meraporus graminicola* Walker or nearly allied insect being parastic upon *Calandra oryzæ*. I do not doubt it was really *P. distinguendus* Först. This winter the stored barley at Poltava Experiment Station was found to be infested by *Calandra granaria*. Among living weevils and injured grains there were found many dead larvæ, evidently sucked by any [*sic*] parasite, and quite a lot of the different pieces of an adult Pteromalin or even uninjured dry specimens. There were, too, hibernating pupæ of this insect, from which adults began to emerge to the end of March. They proved to be identical with *Pteromalus distinguendus* Förster."

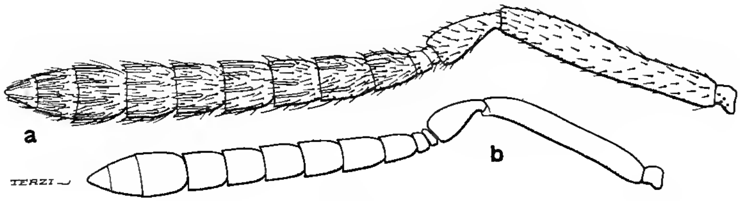

Fig. 6.

Antenna, ♀, of (a) *Lariophagus puncticollis*, and (b) *Lariophagus distinguendus*, outline of average-sized example on same scale as (a).

Vassiliev (**57**, p. 1094) records *L. distinguendus* from *C. granaria* in South Russia. In the following year (**58**, p. 20–23) he deals more fully with the parasites of this weevil and cites Kurdjumov as having determined his material. As Hase (**34**, p. 404) points out, Vayssière's notes on the parasitism of *Eupelmus* on *Calandra* refer to *L. distinguendus*.

In connection with this species the records of *Lariophagus calandræ* may conveniently be noticed. This Pteromalid was described (Report of U.S. Commissioner of Agriculture. Report of the Entomologist for the year 1880, Notes of the Year, p. 273, 1881) as a *Pteromalus* from

Calandra oryzæ in "ears of corn," Hempstead Waller County, Texas (P.S. Clarke Coll.). It is said also to have been bred from *Sitodrepa panicea* (*cf.*, Packard's Guide, p. 470). Pierce (**44**, p. 384) lists *Pteromalus calandræ* How. as a *Meraporus*. Bridwell (**5**, p. 488) doubtfully refers to this species some parasites of *Bruchus quadrimaculatus* infesting pigeon peas in storage (Hawaii). Doane (**17**, p. 312) speaks of it "as the cosmopolitan parasite of grain weevils." His own material came from Australian wheat in California.

I find in the material returned by Dr. Masi that specimens referable to *L. distinguendus* are named *L. calandræ*, having been compared with material determined by Mr. Crawford. More recently Mr. Gahan tells me he has arrived at the conclusion that *calandræ* is synonymous with the older name. It should be noted, however, that *Pteromalus calandræ* was described from a unique ♂ in which the stigmal vein is said to be as long as the marginal, and the abdomen to be "yellow-brown at base, black and shining at tip," a character which suggests rather ♂ *Aplastomorpha*. Even if the proportions of the nervures had been incorrectly stated, I cannot understand how a mistake could occur in reporting the colour of the abdomen. Förster's type of *P. distinguendus* was also a ♂ of which he says definitely "der Hinterleib rundlich, einfarbig dunkelgrün mit violetten schimmer," and in my experience the ♂ of *distinguendus* has the dorsal abdominal surface uniformly opaque, very dark and metallic.

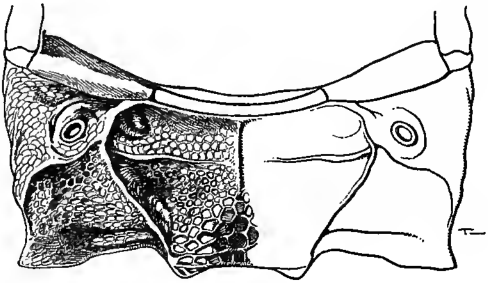

Fig. 7.

Lariophagus distinguendus, ♀, propodeon.

Lariophagus puncticollis Möll.

Arthrolytus puncticollis Möller. Entom. Tidskr., III, p. 180, 1882. Described originally from specimens (♂, ♀) bred from *Sitodrepa* (*Anobium*) *panicea* damaging roots of *Iris florentina* (Sweden). Referring to *Sitodrepa panicea* (Guide, p. 470) Packard records its abundance in several nests of *Vespa* in the Museum of the Peabody Academy, Salem, Mass., where "it was extensively preyed upon by a *Pteromalus*-like Chalcid."

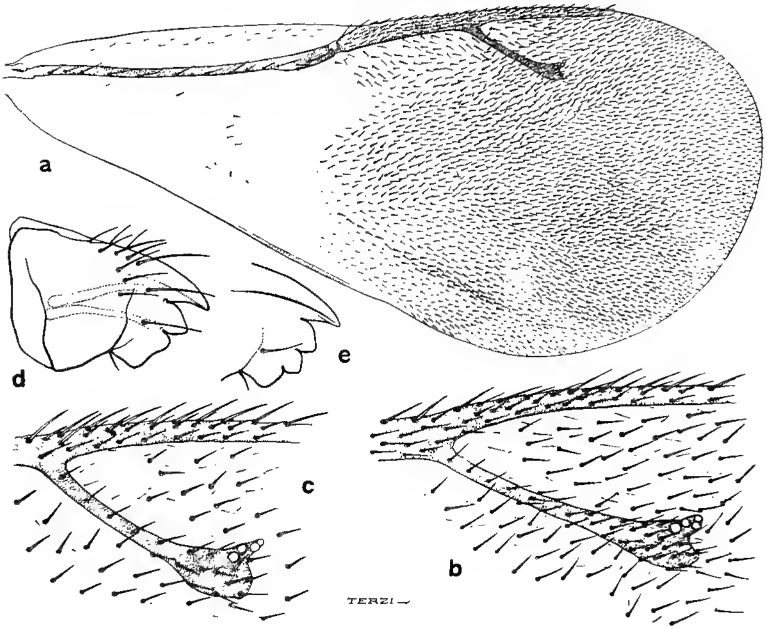

Fig. 8.

Lariophagus puncticollis, ♀, (a) wing, (b) radius, (d)–(e) mandibles, left and right; (c) *Lariophagus distinguendus*, ♀, radius.

Howard and Comstock (**36,** p. 273) and Pierce (**44,** p. 390) possibly record the same parasite under *Pteromalus* or *Meraporus calandræ* How. Kurdjumov (**39,** p. 16) lists *puncticollis* as a species distinct from *distinguendus*. He had seen the type and notes specially the short neck of the propodeon.

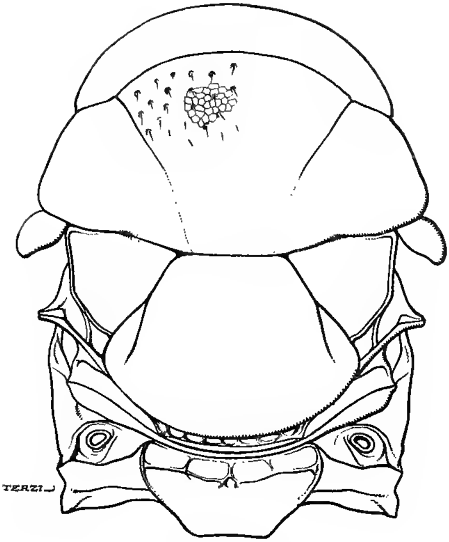

Fig. 9.

Lariophagus distinguendus, ♀, thoracic notum and propodeon, distribution of punctures and size of reticulation indicated.

Ruschka and Fulmek (**51**, p. 401) record *L. puncticollis* on *Sitodrepa panicea*, Krems a. D., Niederösterr., 13.7.1912.

The three specimens which are here referred to Möller's species have already been recorded by Durrant (**21**, p. 2), and were first so named by Mr. Crawford. These examples, remarkably large and stoutly built, are separable at a glance from the long series of *Lariophagus* studied. The most distinct differences are to be found in the chætotaxy of the marginal and radial veins (Fig. 8 (b) and (c)). The antennæ show as compared with *L. distinguendus* no salient differences and the stronger mesonotal puncturation may only be an expression of the greater dimensions. The neck of the propodeon (Fig. 10) is certainly

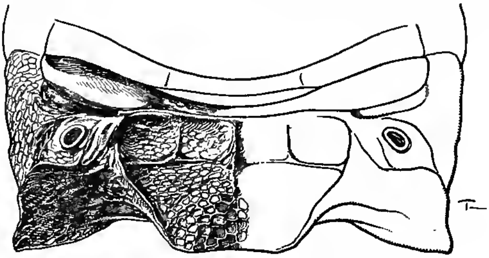

Fig. 10.

Lariophagus puncticollis, ♀, propodeon.

broader apically than in *distinguendus* and thus appears to be shorter than in Förster's species (*cf.*, Kurdjumov's remark *supra*).

Lariophagus utibilis Tucker.

Meraporus utibilis Tucker (E. S.). New parasites of the genus *Meraporus*, Can. Ent. XLII, No. 10, p. 341, October, 1910.

Described originally from seed wheat infested by *Calandra oryzæ*, L. Plano, Texas, 1907–1909, and from infested ear of corn, Shreveport, La., 3.10.1908.

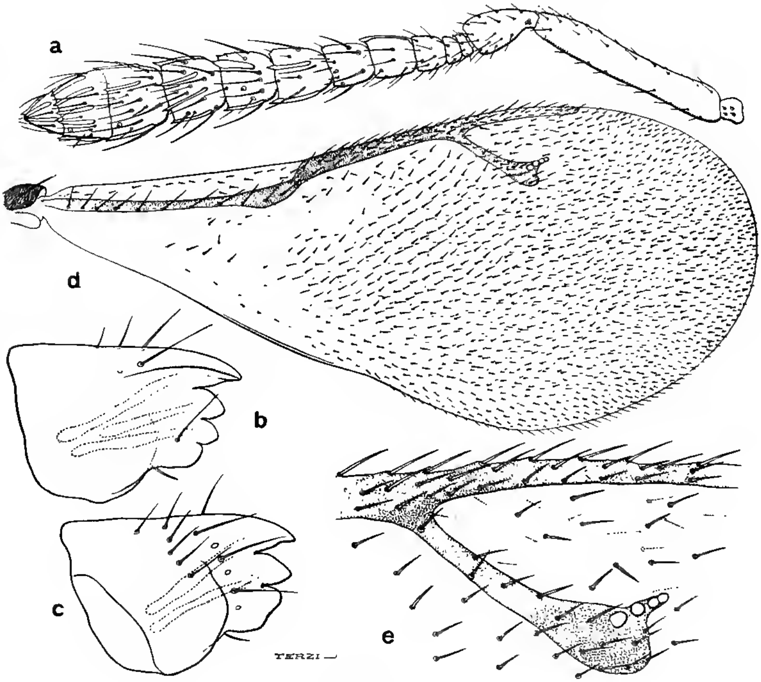

Fig. 11.

Lariophagus utibilis, ♀, (a) antenna, (b)–(c) mandibles—right and left, (d) wing, (e) radius.

Dr. Masi and I have assigned to this species the under-noted examples after comparison with specimens so determined by Mr. Crawford. It should be remarked, however, that the status of *M. utibilis* is at present in dispute. Hase (**34**, p. 406) apparently considers Tucker's description (*vide supra*) applies to *L. distinguendus*, and Mr. Gahan tells me in a recent letter (November, 1920) that he proposes to sink both *utibilis* Tucker and *calandræ* How. as synonyms of *distinguendus* Först.* Not having seen the types of either of these species, I cannot express any opinion on the matter, but in the long series of *Lariophagus* studied are several examples which can be separated, by the characters already given. The most typical examples are decidedly darker blue or more violet in their reflections. Dr. Masi thinks this form worthy of separation, but at present I do not care to propose a name.

Apart from the amount of metallic reflection shown, the general coloration in *Lariophagus* is very constant. In *puncticollis* the femora, particularly of the hind legs, are much darkened—chocolate brown, whereas in *distinguendus* they are ferruginous—sometimes hardly darker than the tibiæ. In *utibilis* the femora are dark and (in the ♂) the tibiæ to a great extent also.

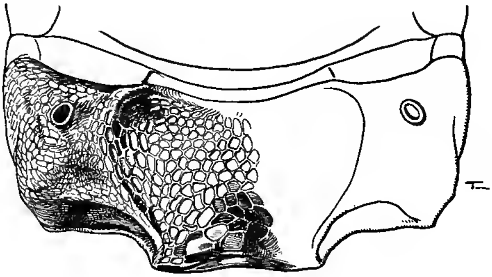

Fig. 12.
Lariophagus utibilis, ♀, propodeon.

It will, I think, be necessary to carry out breeding experiments with these three forms of *Lariophagus* before their status can be determined.

SPALANGIIDÆ.

CHÆTOSPILA Westw.

Chætospila Westwood (J. O.). Thesaurus Entomologicus Oxoniensis, p. 137, Plate XXV, fig. 10, 1874. Genotype *Chætospila elegans* Westw., *loc. cit.*

Chætospila elegans Westw.

The original record runs "Habitat parasitice in Zeæ Maydis seminibus (D. Raddon). In Mus. Hopeiano Oxoniæ (olim nostræ)."

It is not a little remarkable that this species, so clearly illustrated and characterized by Westwood, has remained almost unnoticed in subsequent literature. As the species appears to be widely spread and not rare, the probabilities are that it has been redescribed. Of one synonym there can be little doubt, *viz.*, *Spalangiomorpha fasciatipennis* Gir. Both genus and species should, I think, be sunk. The characters given for *Spalangiomorpha* (**30**, p. 333) are exactly those of *Chætospila*, and I see nothing discrepant between the descriptions of the genotype *S. fasciatipennis* and *C. elegans* which occurs typically in N.S.W. (*vide infra*).

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* *cf.* Gahan, A. B., "On the identity of several species of Chalcidoidea (Hymenoptera)." Proc. Ent. Soc. Wash., Vol. XXII, No. 9, December, 1920. "The type of *utibilis* is a rather small and poorly developed specimen" (*i.e.*, of *distinguendus*), p. 239. Gahan also (*ibid.*) treats *Aplastomorpha australiensis* Gir. as a synonym of *A. vandinei*, and notes that Girault himself (Insec. Inscit. Menst., Vol. V, p. 152, 1917) had already come to this conclusion.

Girault's specimens were all from Queensland. He found the species (**30**, p. 334) on windows of grocery stores rather commonly, and identified it again in material (sent by G. F. Hill) reared from "grain moth." His later reference (**31**, p. 345) and description of the ♂ may refer to another species, as the ♂ antennæ are said to be 11-jointed.

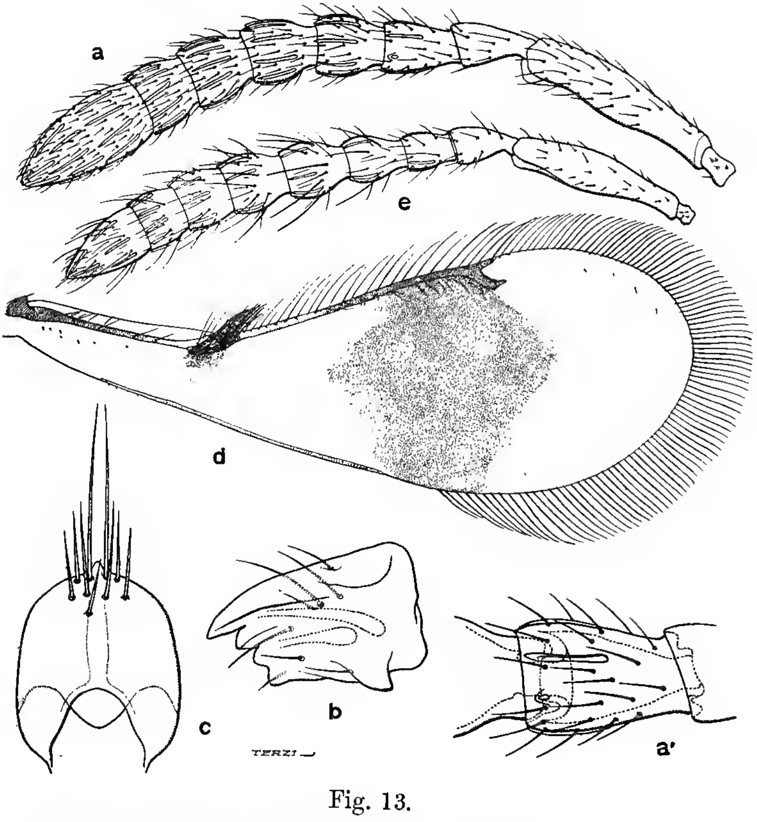

Fig. 13.

Chætospila elegans, ♀, (a) antenna, (a′) first funicular joint, (b) left mandible, (c) labrum, (d) wing, (e) ♂ antenna.

Hill (**35**, p. 16) records *S. fasciatipennis* from "weevil-infested grain."

Bridwell (**6**, p. 19) says that in Hawaii *C. elegans* is a parasite of *Bruchus quadrimaculatus* in pigeon and cow peas in storage, and also of *Calandra oryzæ*. He adds that as a controller it is of no practical use.

Colour notes.— ♀, ♂. Head and thorax (superiorly) and abdomen (entirely) and tip of ovipositor broadly, blackish-brown with purplish or violet-black metallic reflections. Pronotum, propodeon at the sides, petiole and base of ovipositor, brown, as are also the under (posterior) aspect of the porrect head, and the thoracic sternopleura. Scape, pedicel, first and basal half of second funicular joints, brown; remainder of funicle very dark brown. Fore and hind coxæ, very pale, the latter with some metallic reflections superiorly. Mid coxæ and rest of legs, clear brown, the hind femora sometimes a little infuscated above. Wings, scales of tufts at junction of submarginal and marginal nearly black; hyaline, with a broad median brown completely transverse band from about the middle of the marginal vein to the end of the postmarginal.

Vespoidea.

BETHYLIDÆ.

Rhabdepyris zeæ Turner and Waterston, *sp. n.*

♀. Nigra, nitida; mandibulis, scapo, apice, flagello articulis duobus basalibus; tegulis, tibiis tarsisque pallide brunneo-testaceis; alis hyalinis iridescentibus, venis pallide testaceis, stigmate fusco. Long. 3 mm.

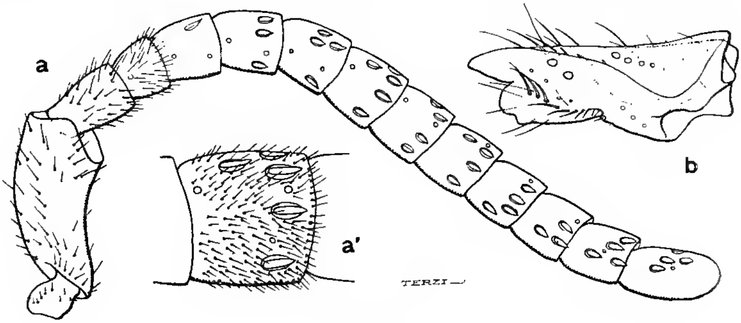

Fig. 14.

Rhabdepyris zeæ, ♀, (a) antenna, (a′) fifth funicular joint from the pedicel, (b) mandible.

♀. Head distinctly longer than the greatest breadth, somewhat narrowed both posteriorly and anteriorly, very finely and rather sparsely punctured, without a frontal sulcus. Eyes separated from the hind margin of the head by a distance not quite equal to half of their own length; posterior ocelli rather far apart, almost touching the hind margin of the head. Mandibles tridentate, the outer tooth long and acute, the second broad but much shorter, the third very short. First joint of the flagellum long, a little longer than the third, the second very short, scarcely half as long as the first. Pronotum a little shorter than the greatest breadth, narrowed and rounded anteriorly, finely and sparsely punctured; mesonotum with two well-defined parapsidal furrows. Scutellum smooth, with a short, but very deep transverse groove at the base. Median segment as long as broad, distinctly margined laterally and posteriorly; the dorsal surface finely regulose, with a low median carina from base to apex; and on each side near the lateral margin is a low longitudinal carina which diverges slightly from the side towards the apex; the surface of the apical truncation finely transversely rugulose, with a low median carina. Abdomen smooth and shining, the apical segments with sparse microscopic punctures. Hind tarsal ungues small, not strongly curved; with a

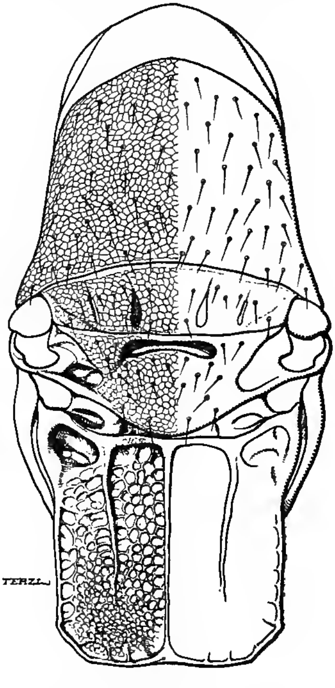

Fig. 15.
Rhabdepyris zeæ, ♀, propodeon.

single, small, erect tooth near the middle of the inner margin. Radius long, about three times as long as the basal nervure; the nervulus forming an acute angle with the basal nervure, leaving a deep emargination between the apex of the median and that of the submedian cell.

Hab.—In maize received at Liverpool in December, 1916, from West Africa. (Roy. Soc. Grain Pest Committee, No. 170).—One specimen.

Type ♀ in British Museum (Nat. Hist.). Card mounted, with wing, antenna, mandible, and hind leg on slide.

This species may be recognized by the proportions of the antennal joints, the peculiar mandible, and the distinctive sculpture of the thorax and propodeon.

Rhabdepyris zeæ, sp. n., is almost certainly a parasite of *Calandra oryzæ* L., but it may be remarked that *Tribolium castaneum* Herbst., and *Læmophlœus ferrugineus* Steph., occurred in the same sample.

Sitotroga cerealella Oliv. (Lep.) did not occur.

CEPHALONOMIA Westw.

At least two species have been taken, reared from grain-destroying Coleoptera. This genus is poorly represented in the National Collection, and it has been impossible up to the present to determine the material falling here. A supplementary note, however, will later be published dealing with this genus.

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January, 1921.

INSECTS ASSOCIATED WITH GRAIN, &c.

By JOHN HARTLEY DURRANT, Department of Entomology, British Museum (Natural History).

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My work has been for the most part the drudgery of detail: the cataloguing of more than five hundred samples of grain, &c., the separation of the insects from the grain and the determination of many thousands of specimens, keeping records of those which were associated. In this work I received much assistance from Dr. G. C. Dixon and Miss B. M. Willis, to whom I wish to express my thanks, as also to Messrs. G. J. Arrow, K. G. Blair, E. G. Baker, Dr. C. J. Gahan and Dr. J. Waterston, who have assisted me in determining critical species. Dr. Waterston's report will be of the greatest service to all who have to determine the Parasitic Hymenoptera associated with grain pests.

The origin of the samples in which these Hymenoptera occurred, and the enumeration of the Coleoptera, &c., follows after a classified list of all the species met with, giving in tabular form as much information as was possible. In this table the first column gives the name; the second indicates the nature of the insect—the following abbreviations being used: * = pest, S = scavenger, P = parasite, Pr = predaceous; the third column shows the nature of the sample in which the insect occurred, the abbreviations being W = wheat, M = maize, B = barley, O = oats, F = flour, Bi = biscuits, Mc = paste (macaroni), P = pease, L = lentils, Be = beans; the fourth column shows the geographical distribution, E = Europe, I = India, Af = Africa, Au = Australia, Am N = N. America, Am. S = S. America.

Insects found.	Nature of Insect. (Pest, &c.)	Nature of Sample. (Wheat, Maize, &c.)	Distribution. (Europe, Asia, Africa, &c.)
COLEOPTERA.			
Sitodrepa panicea Linné ...	—	W, Bi, M	E, I
Lasioderma serricorne Fabr.	—	Bi, Be	E
Rhizopertha dominica Fabr.	*	W, M, Bi, Be, L	E, I, Af, Au, Am S
Necrobia rufipes De Geer ...	S, P	W	Au
Ptinus fur Linné	S	W	E
P. tectus Boieldieu	S	W, M, Bi, M	E, Au, Am S
Niptus hololeucos Fald. ...	S	W, M.	E, I
Carpophilus dimidiatus Fabr.	—	W	I

Insects found.	Nature of Insect. (Pest, &c.)	Nature of Sample (Wheat, Maize, &c.)	Distribution. (Europe, Asia, Africa, &c.)
COLEOPTERA—*continued.*			
Nitidula carniaria Sch. Er. ...	—	L	Af
Tenebrioides mauritanicus L.	Pr	W, M, F, Bi, L	E,I,Af,Au,AmN,AmS
Læmophlœus pusillus Schön.	S, Pr	W, M	I, Af, Au, Am S
L. ferrugineus Stephens ...	S, Pr	W, M	I, Af, Au, Am N, Am S
Silvanus surinamensis Linné	*, S	W, M, O, Bi, Mc, L	E, Af, Au, Am S
Cathartus quadricollis Guérin	—	M	Af
C. advena Waltl.	—	W, Be	Au
Typhæa stercorea Linné ..	—	W	I, Au
Trogoderma khapra Arrow ...	*	W	E, I
Latheticus oryzæ Waterhouse	—	W	I, Au,
Bruchus analis Fabricius ...	—	W	I
B. chinensis Linné	—	W, Be, L	I, Hankow
B. incarnatus Boheman ...	—	Be	Af
B. lentis Frölich	*	L	Af
B. obtectus Say	—	Be	E
B. pisorum Linné	*	P, L	E, Af
Spermophagus subfasciatus B	—	Bi	Am S
Alphitobius diaperinus Pan.	—	W, L	E, Au
Gnathocerus cornutus Fabr.	*	F	E
Echocerus maxillosus Fabr....	—	M	Af
Tribolium castaneum Hbst.	*, S	W, M, Bi, Be	E,I,Af,Au,AmN,AmS
T. confusum Duval	*, S	W, M, Bi, L	E, Af, Au
Palorus subdepressus Wlstn.	—	L	Af
P. ratzeburgi Wissmann ...	—	L	Af
Anthicus floralis Linné ...	—	W	Au
A. elegans Lea	—	W	Au
Calandra oryzæ Linné ...	*	W, M, Bi, Mc, Be, L	E,I,Af,Au,AmN,AmS
C. granaria Linné	*	W, M, O, Bi	E, I, Au, Am N, Am S
LEPIDOPTERA.			
Corcyra cephalonica Sta. ...	*	M, Bi	E
Plodia interpunctella Hüb. ...	*	M	E, Af
Ephestia kühniella Zeller ...	*	W, F, Bi, Mc	E, Am N
E. cautella Walker	*	Bi	E, I
E. elutella Hübner ...	*	Bi	E
Sitotroga cerealella Olvr. ..	*	W, M	E, I, Af, Am N, Am S
Borkhausenia pseudospret. S	S	—	E
Tinea granella Linné... ...	—	W	E
HYMENOPTERA.			
Habrobracon brevicornis W.	P	W, F, Bi	E
Nemeritas canescens Gr. ...	P	W, F	E
Bruchobius laticeps Ashmead	P	Be	Af, Am S
Lariophagus puncticollis M....	P	Bi	E
L. distinguendus Förster ...	P	W, M, L	I, Af, Au
L. sp. (utibilis Tucker)	P	W	I, Au
Aplastomorpha vandinei T...	P	W, M, L	I, Af, Au
Chætospila elegans Westwood	P	W	I, Af, Au, Java
Rhabdepyris zeæ, sp.n. T.&W.	P	W, M	I, Af, Au
Cephalonomia sp.	P	W	Au

NOTES ON ABOVE LIST.

Calandra oryzæ L., *Calandra granaria* L., *Rhizopertha dominica* F., and *Trogoderma khapra* Arrow, are known to be the really serious pests of grain, and of these *Calandra oryzæ* probably occasions more loss than all the other species which occur in grain combined.

Tribolium, *Silvanus*, and *Latheticus* are more scavengers than primary pests, destroying grain which has been injured by the primary pests. These species are, however, undoubtedly real pests of flour, biscuit, and other products. Mr. F. Laing, while agreeing in general with these remarks, believes that *Tribolium ferrugineum* can be induced to attack grain. Great numbers of *Tribolium ferrugineum* occurred in the samples, but I have been greatly surprised at the rarity of *Tribolium confusum*—including fragments, only eleven specimens were met with in the large number of samples examined.

Trogoderma khapra Arrow.—When describing this species [Ann. Mag. N. H. **(8 s.) 19,** 482 (1917)] Arrow wrote "there is no evidence that it is able to perpetuate itself in Europe, nor has it been found in grain imported from other regions than India." Mr. F. Laing informs me that *khapra* is causing very great damage to malt in the brewing district around Burton, where it is undoubtedly reproducing itself under the conditions prevailing there. He understands that the species was originally introduced into the breweries in consignments of barley from India. I may remark that larval remains in wheat samples from Queensland were, in my opinion, *Trogoderma khapra*, but whether established there or only infesting the ship I am unable to say. Commander J. J. Walker informs me that he took this species a good many years ago at Strood. It was also met with during the Army Biscuit Enquiry, but Dr. G. C. Dixon was the first to find the larva and breed the species in this country. I have also bred many in my room in the Museum, the average temperature of which is 63° F.

Tenebrioides mauritanicus L.—This species has long been reputed injurious, but in my experience it is a predaceous insect, not a pest. I have observed both beetle and larva devouring beetles (*Tribolium ferrugineum*, *Silvanus surinamensis*, &c.), and also the larvæ and pupæ of *Ephestia kühniella.* If placed in flour in a large glass bottle the larva of *tenebrioides* is very restless, making long burrows throughout the flour, evidently searching for insect prey: if it were satisfied with flour as a diet it would be sedentary and there would be no reason for this restlessness and the long burrows.

Cathartus quadricollis Guér., *Echocerus maxillosus* F., and *Anthicus elegans* Lea are recorded, apparently for the first time in this country, while *Trogoderma khapra* Arrow and *Rhabdepyris zeæ* Turner and Waterston have been described as new.

Tinea granella L.—A single specimen was bred: this used to be reputed a serious grain pest.

Lariophagus spp. These *Pteromalidæ* were observed in millions in the docks, blackening the sacks from which they had emerged.

RECORD OF SAMPLES CONTAINING HYMENOPTERA SHOWING THEIR ORIGIN AND THE LEPIDOPTERA AND COLEOPTERA WITH WHICH THEY WERE ASSOCIATED :—

Ichneumonoidea.

Habrobracon brevicornis Wesm.

Biscuit, 457, London, *ex* London *via* Gibraltar.
Ephestia elutella Hb., *ex* 27.VIII.1912 (Drnt.).

Biscuit, 458, London, *ex* London *via* S. Africa.
Ephestia kühniella Z., *ex* 15.V.1913 to 5.VI.1913 (Drnt.).

Flour, London.
A few specimens observed in mills.

Nemeritis canescens Grav.

Flour, London.
Ephestia kühniella Z. Bred freely from flour damaged by this species, also observed in considerable numbers in mills in the London district.

Chalcidoidea.

Bruchobius laticeps Ashm.

Beans, 29 (= Vicia faba L.), London, *ex* Alexandria.
Bruchus incarnatus.

Beans, 173 (= Phaseolus lunatus L.), Liverpool, *ex* Peru.
Spermophagus subfasciatus.

Beans, 411 (= Dolichos sesquipedalis L.), London, *ex* Brazil
Spermophagus subfasciatus; Bruchus obtectus.

Lariophagus puncticollis Möller.

Biscuit, 456, London, *ex* Malta.
Sitodrepa panicea, excl., 11.V.1908 (W. W. O. Beveridge).

Lariophagus distinguendus Först.

Maize, 8, London, *ex* Alexandria.
Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis.
Læmophlœus ferrugineus.
Aplastomorpha vandinei Tuck. also occurred.

Lentils, 30 (= Ervum lens L.).
Calandra oryzæ; Bruchus lentis, incarnatus; Tribolium confusum; Silvanus surinamensis; Palorus subdepressus, ratzeburgi; Nitidula carniaria; Læmophlœus pusillus.
Aplastomorpha vandinei Tuck. also occurred.

Wheat, 205, London, *ex* Fremantle.
Calandra oryzæ; Tribolium castaneum; Læmophlœus ferrugineus.

Wheat, 213, London, *ex* Port Adelaide.
Calandra oryzæ, granaria; Silvanus surinamensis.

Wheat, 223, London, *ex* Albany and Fremantle.
Calandra oryzæ; Tribolium castaneum.
Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 224, Hull, *ex* Adelaide.
Calandra oryzæ; Silvanus surinamensis; Cathartus advena.

Wheat, 225, Hull, *ex* Adelaide.
Calandra oryzæ, granaria; Læmophlœus pusillus.
Lariophagus sp. (utibilis Tuck.) and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 229, Dublin, *ex* Sydney.
Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.
Aplastomorpha vandinei Tuck. also occurred.

Wheat, 230, London, *ex* Sydney.
Calandra oryzæ; Rhizopertha dominica; Silvanus surinamensis; Læmophlœus pusillus.

Wheat, 231, Hull, *ex* Melbourne.
Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Læmophlœus ferrugineus.

Wheat, 236, Dublin, *ex* Sydney.
Calandra oryzæ, granaria; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.
Aplastomorpha vandinei Tuck. also occurred.

Wheat, 246, Glasgow, *ex* Sydney.
Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.

Wheat, 253, Liverpool, *ex* Sydney.
Calandra oryzæ, granaria; Silvanus surinamensis; Læmophlœus pusillus.

Wheat, 260, London, *ex* Sydney.
Calandra oryzæ, granaria.

Wheat, 262, London, *ex* Sydney.
Calandra oryzæ; Tribolium confusum; Læmophlœus pusillus.
Lariophagus sp. (utibilis Tuck.), *Aplastomorpha vandinei* Tuck. and *Cephalonomia sp.* also occurred.

Wheat, 263, Hull, *ex* Sydney.
Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Læmophlœus pusillus; Cathartus advena.
Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 265, Birkenhead, *ex* Fremantle.
Calandra oryzæ; Rhizopertha dominica.
Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 266, London, *ex* Sydney.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Læmophlœus pusillus; Anthicus floralis.

Lariophagus sp. (utibilis Tuck.) and *Aplastomorpha vandinei* Tuck, also occurred.

Wheat, 268, Liverpool, *ex* Port Adelaide.

Calandra oryzæ, granaria; Tribolium castaneum.

Lariophagus sp. (utibilis Tuck.), *Aplastomorpha vandinei* Tuck. and *Chætospila elegans* Wstwd. also occurred.

Wheat, 290, Manchester, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Cathartus advena.

Lariophagus sp. (utibilis Tuck.) and *Chætospila elegans* Wstwd. also occurred.

Wheat, 291, Belfast, *ex* Port Pirie (S. Australia).

Calandra oryzæ, granaria; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus sp. (utibilis Tuck.) and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 292, London, *ex* Sydney.

Calandra oryzæ, granaria; Silvanus surinamensis; Latheticus oryzæ; Cathartus advena.

Lariophagus sp. (utibilis Tuck.) and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 319, London, *ex* Sydney.

Calandra oryzæ.

Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 321, London, *ex* Port Adelaide.

Calandra oryzæ; Læmophlœus pusillus.

Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 322, Manchester, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus ferrugineus; Cathartus advena.

Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 324, Plymouth, *ex* Sydney.

Calandra oryzæ, granaria; Silvanus surinamensis; Læmophlœus pusillus; Ptinus tectus.

Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 325, Dublin, *ex* Port Adelaide.

Calandra oryzæ; Tribolium castaneum; Læmophlœus pusillus.

Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 337, London, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis.

Lariophagus sp. (utibilis Tuck.) and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 338, Liverpool, *ex* Melbourne.

Calandra oryzæ; Læmophlœus ferrugineus.

Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 341, Liverpool, *ex* Sydney.

Calandra oryzæ; Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus sp. (utibilis Tuck.) and *Chætospila elegans* Wstwd. also occurred.

Wheat, 342, Liverpool, *ex* Williamstown (Victoria).

Calandra granaria; Silvanus surinamensis.

Chætospila elegans Wstwd. also occurred.

Wheat, 344, Cardiff, *ex* Port Pirie (S. Australia).

Calandra oryzæ; Tribolium castaneum.

Wheat, 347, Liverpool, *ex* Fremantle.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Tenebrioides mauritanicus.

Lariophagus sp. (utibilis Tuck.) and *Cephalonomia sp.* also occurred.

Wheat, 348, Liverpool, *ex* Fremantle.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Læmophlœus pusillus; Carpophilus dimidiatus; Tenebrioides mauritanicus.

Cephalonomia sp. also occurred.

Wheat, 349, Liverpool, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Carpophilus dimidiatus.

Lariophagus sp. (utibilis Tuck.) and *Cephalonomia sp.* also occurred.

Wheat, 351, Glasgow, *ex* Port Adelaide.

Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Carpophilus dimidiatus; Anthicus floralis.

Aplastomorpha vandinei Tuck. and *Chætospila elegans* Wstwd. also occurred.

Wheat, 353, Belfast, *ex* Melbourne.

Calandra oryzæ, granaria.

Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 354, Bristol, *ex* Melbourne.

Calandra oryzæ, Læmophlœus pusillus.

Wheat, 355, Liverpool, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 356, Glasgow, *ex* Sydney.

Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Carpophilus dimidiatus.

Lariophagus sp. (utibilis Tuck.) and *Chætospila elegans* Wstwd. also occurred.

Wheat, 363, London, *ex* Sydney.

Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.

Aplastomorpha vandinei Tuck. also occurred.

Wheat, 364, Southampton, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Læmophlœus pusillus.

Wheat, 365, Plymouth, *ex* Melbourne.

Calandra granaria; Tribolium castaneum: Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus sp. (utibilis Tuck.) also occurred

Wheat, 366, Liverpool, *ex* Sydney.

Calandra oryzæ, granaria; Silvanus surinamensis; Ptinus tectus.

Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 369, Falmouth, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Læmophlœus pusillus.

Wheat, 370, Falmouth, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Cathartus advena; Carpophilus dimidiatus; Anthicus elegans; Tenebrioides mauritanicus.

Lariophagus sp. (utibilis Tuck.) and *Cephalonomia sp.* also occurred.

Wheat, 371, London, *ex* Adelaide.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis.

Lariophagus sp. (utibilis Tuck.) and *Cephalonomia sp.* also occurred.

Wheat, 378, London, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus sp. (utibilis Tuck.) and *Cephalonomia sp.* also occurred.

Wheat, 379, Sunderland, *ex* Fremantle.

Calandra oryzæ, granaria; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Carpophilus dimidiatus (⊕ Sitotroga cerealella).

Lariophagus sp. (utibilis Tuck.) and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 380, Sunderland, *ex* Fremantle.

Calandra oryzæ; Tribolium castaneum; Læmophlœus pusillus; Carpophilus dimidiatus; Typhæa stereorea; Tenebrioides mauritanicus.

Lariophagus sp. (utibilis Tuck.), *Chætospila elegans* Wstwd. and *Rhabdepyris zeæ* Turner and Waterston also occurred.

Wheat, 381, Sunderland, *ex* Fremantle.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Alphitobius diaperinus; Tenebrioides mauritanicus.

Lariophagus sp. (utibilis Tuck.) and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 382, London, *ex* Sydney.
Calandra oryzæ, granaria; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Carpophilus dimidiatus.
Lariophagus sp. (utibilis Tuck.), *Chætospila elegans* Wstwd. and *Cephalonomia sp.* also occurred.

Wheat, 383, Southampton, *ex* Sydney.
Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.
Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 384, Glasgow, *ex* Sydney.
Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.
Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 385, Glasgow, *ex* Sydney.
Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Cathartus advena; Tenebrioides mauritanicus.
Lariophagus sp. (utibilis Tuck.) and *Chætospila elegans* also occurred.

Wheat, 386, Glasgow, *ex* Geelong (Victoria).
Calandra granaria; Rhizopertha dominica; Silvanus surinamensis: Læmophlœus pusillus.
Cephalonomia sp. also occurred.

Wheat, 387, Glasgow, *ex* Geelong (Victoria).
Calandra granaria; Tribolium castaneum, confusum; Silvanus surinamensis; Læmophlœus pusillus; Tenebrioides mauritanicus.
Lariophagus sp. (utibilis Tuck.) and *Cephalonomia sp.* also occurred.

Wheat, 388, Sunderland, *ex* Fremantle.
Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Tenebrioides mauritanicus.
Lariophagus sp. (utibilis Tuck.), *Aplastomorpha vandinei* Tuck. and *Cephalonomia sp.* also occurred.

Wheat, 389, Sunderland, *ex* Fremantle.
Calandra oryzæ; Tribolium castaneum; Læmophlœus pusillus; Tenebrioides mauritanicus.
Lariophagus sp. (utibilis Tuck.) and *Cephalonomia sp.* also occurred.

Wheat, 390, Manchester, *ex* Sydney.
Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Læmophlœus pusillus; Cathartus advena; Tenebrioides mauritanicus.
Cephalonomia sp. also occurred.

Wheat, 421, London, *ex* Karachi.
Calandra oryzæ, granaria; Rhizopertha dominica; Trogoderma khapra; Tribolium castaneum; Bruchus pisorum, analis.
[N.B.—One bean occurred in this sample.]

Wheat, 425, London, *ex* Bombay.

Calandra oryzæ; Rhizopertha dominica; Trogoderma khapra; Tribolium castaneum; Silvanus surinamensis.

Lariophagus sp. (utibilis Tuck.).

Wheat, 222, London, *ex* Fremantle and Albany.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.

Cephalonomia sp. also occurred.

Wheat, 223, London, *ex* Albany and Fremantle.

Calandra oryzæ; Tribolium castaneum.

Lariophagus distinguendus Först. also occurred.

Wheat, 225, Hull, *ex* Adelaide.

Calandra oryzæ, granaria; Læmophlœus pusillus.

Lariophagus distinguendus Först. and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 231, Hull, *ex* Melbourne.

Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus ferrugineus.

Lariophagus distinguendus Först. also occurred.

Wheat, 246, Glasgow, *ex* Sydney.

Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus distinguendus Först. also occurred.

Wheat, 256, Avonmouth, *ex* Adelaide.

Calandra oryzæ; Silvanus surinamensis; Necrobia rufipes.

Wheat, 262, London, *ex* Sydney.

Calandra oryzæ; Tribolium confusum; Læmophlœus pusillus.

Lariophagus distinguendus Först., *Aplastomorpha vandinei* Tuck. and *Cephalonomia sp.* also occurred.

Wheat, 263, Hull, *ex* Sydney.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Læmophlœus pusillus; Catharthus advena.

Lariophagus distinguendus Forst. also occurred.

Wheat, 265, Birkenhead, *ex* Fremantle.

Calandra oryzæ; Rhizopertha dominica.

Lariophagus distinguendus Först. also occurred.

Wheat, 266, London, *ex* Sydney.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Læmophlœus pusillus; Anthicus floralis.

Lariophagus distinguendus Först., *Aplastomorpha vandinei* Tuck. and *Cephalonomia sp.* also occurred.

Wheat, 268, Liverpool, *ex* Port Adelaide.

Calandra oryzæ, granaria; Tribolium castaneum.

Lariophagus distinguendus Först., *Aplastomorpha vandinei* Tuck. and *Chætospila elegans* Wstwd. also occurred.

Wheat, 290, Manchester, *ex* Sydney.
Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.
Lariophagus distinguendus Först. and *Chætospila elegans* Wstwd. also occurred.

Wheat, 291, Belfast, *ex* Port Pirie (South Australia).
Calandra oryzæ, granaria; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.
Lariophagus distinguendus Först. and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 292, London, *ex* Sydney.
Calandra oryzæ, granaria; Silvanus surinamensis; Latheticus oryzæ Catharthus advena.
Lariophagus distinguendus Först., and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 301, Liverpool, *ex* Sydney.
Calandra oryzæ; Silvanus surinamensis; Læmophlœus pusillus.

Wheat, 316, Liverpool, *ex* Port Adelaide.
Calandra oryzæ, granaria; Rhizopertha dominica; Læmophlœus ferrugineus.

Wheat, 317, London, *ex* Sydney.
Calandra oryzæ, granaria; Tribolium castaneum.

Wheat, 319, London, *ex* Sydney.
Calandra oryzæ.
Lariophagus distinguendus Först. also occurred.

Wheat, 321, London, *ex* Port Adelaide.
Calandra oryzæ; Læmophlœus pusillus.

Wheat, 322, Manchester *ex* Sydney.
Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus ferrugineus; Cathartus advena.
Lariophagus distinguendus Först. also occurred.

Wheat, 324, Plymouth, *ex* Sydney.
Calandra oryzæ, granaria; Silvanus surinamensis; Læmophlœus pusillus; Ptinus tectus.
Lariophagus distinguendus Först. and *Cephalonomia sp.* also occurred.

Wheat, 325, Dublin, *ex* Port Adelaide.
Calandra oryzæ; Tribolium castaneum; Læmophlœus pusillus.
Lariophagus distinguendus Först. also occurred.

Wheat, 326, London, *ex* Sydney.
Calandra oryzæ.

Wheat, 337, London, *ex* Sydney.
Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis.
Lariophagus distinguendus Först. and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 338, Liverpool, *ex* Melbourne.
Calandra oryzæ; Læmophlœus ferrugineus.
Lariophagus distinguendus Först. also occurred.

Wheat, 341, Liverpool, *ex* Sydney.
Calandra oryzæ; Silvanus surinamensis; Læmophlœus pusillus.
Lariophagus distinguendus Först. and *Chætospila elegans* Wstwd. also occurred.

Wheat, 347, Liverpool, *ex* Fremantle.
Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Tenebrioides mauritanicus.
Lariophagus distinguendus Först. and *Cephalonomia sp.* also occurred

Wheat, 349, Liverpool, *ex* Sydney.
Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Carpophilus dimidiatus.
Lariophagus distinguendus Först. and *Cephalonomia sp.* also occurred

Wheat, 353, Belfast, *ex* Melbourne.
Calandra oryzæ, granaria.
Lariophagus distinguendus Forst. also occurred.

Wheat, 355, Liverpool, *ex* Sydney.
Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.
Lariophagus distinguendus Först. also occurred.

Wheat, 356, Glasgow, *ex* Sydney.
Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.
Lariophagus distinguendus Först. and *Chætospila elegans* Wstwd. also occurred.

Wheat, 357, Plymouth, *ex* Melbourne.
Calandra oryzæ; Tribolium castaneum; Læmophlœus pusillus.

Wheat, 359, Leghorn, *ex* Karachi.
Calandra oryzæ; Rhizopertha dominica; Trogoderma khapra.
Chætospila elegans Wstwd. also occurred.

Wheat, 365, Plymouth, *ex* Melbourne.
Calandra granaria; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.
Lariophagus distinguendus Först. also occurred.

Wheat, 366, Liverpool, *ex* Sydney.
Calandra oryzæ, granaria; Silvanus surinamensis; Ptinus tectus.
Lariophagus distinguendus Först. also occurred.

Wheat, 368, Cork, *ex* Melbourne.
Calandra oryzæ.

Wheat, 370, Falmouth, *ex* Sydney.
Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis;

Læmophlœus pusillus; Catharthus advena; Carpophilus dimidiatus; Anthicus elegans; Tenebrioides mauritanicus.

Lariophagus distinguendus Först. and *Cephalonomia sp.* also occurred

Wheat, 371, London, *ex* Adelaide.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis.

Lariophagus distinguendus Först. and *Cephalonomia sp.* also occurred.

Wheat, 378, London, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus distinguendus Först. and *Cephalonomia sp.* also occurred.

Wheat, 379, Sunderland, *ex* Fremantle.

Calandra oryzæ, granaria; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Carpophilus dimidiatus (⊕ Sitotroga cerealella).

Lariophagus distinguendus Först. and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 380, Sunderland, *ex* Fremantle.

Calendra oryzæ; Tribolium castaneum; Læmophlœus pusillus, Carpophilus dimidiatus; Typhæa stercorea; Tenebrioides mauritanicus.

Lariophagus distinguendus Först., *Chætospila elegans* Wstwd. and *Rhabdepyris zeæ* Turner and Waterston also occurred.

Wheat, 381, Sunderland *ex* Fremantle.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Alphitobius diaperinus; Tenebrioides mauritanicus.

Lariophagus distinguendus Först. and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 382, London, *ex* Sydney.

Calandra oryzæ, granaria; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Carpophilus dimidiatus.

Lariophagus distinguendus Först., *Chætospila elegans* Wstwd. and *Cephalonomia sp.* also occurred.

Wheat, 383, Southampton, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus distinguendus Först. also occurred.

Wheat, 384, Glasgow, *ex* Sydney.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus distinguendus Först. and *Cephalonomia sp.* also occurred.

Wheat, 385, Glasgow, *ex* Sydney.

Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Cathartus advena; Tenebrioides mauritanicus.

Lariophagus distinguendus Först. and *Chætospila elegans* Wstwd. also occurred.

Wheat, 387, Glasgow, *ex* Victoria.

Calandra granaria; Tribolium castaneum, confusum; Silvanus surinamensis; Læmophlœus pusillus; Tenebrioides mauritanicus.

Lariophagus distinguendus Först. and *Cephalonomia sp.* also occurred.

Wheat, 388, Sunderland, *ex* Fremantle.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Tenebrioides mauritanicus.

Lariophagus distinguendus Först., *Aplastomorpha vandinei* Tuck. and *Cephalonomia sp.* also occurred.

Wheat, 389, Sunderland, *ex* Fremantle.

Calandra oryzæ; Tribolium castaneum; Læmophlœus pusillus; Tenebrioides mauritanicus.

Lariophagus distinguendus Först. and *Cephalonomia sp.* also occurred.

Aplastomorpha vandinei Tuck. (=pratti Crawf.).

Maize, 8, London, *ex* Alexandria.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis Læmophlœus ferrugineus; Tenebrioides mauritanicus.

Lariophagus distinguendus Först. also occurred.

Lentils, 30, (= Ervum lens L.), London, *ex* Alexandria.

Calandra oryzæ; Bruchus lentis, incarnatus; Tribolium confusum; Silvanus surinamensis; Læmophlœus pusillus; Palorus subdepressus, ratzeburgi; Nitidula carniaria.

Lariophagus distinguendus Först. also occurred.

Wheat, 184, Hull, *ex* Bombay.

Calandra oryzæ, granaria; Rhizopertha dominica; Trogoderma khapra; Tribolium castaneum; Latheticus oryzæ.

Wheat, 225, Hull, *ex* Adelaide.

Calandra oryzæ, granaria; Læmophlœus pusillus.

Lariophagus distinguendus Först. and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 229, Dublin, *ex* Sydney.

Calandræ oryzæ; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus distinguendus Först. also occurred.

Wheat, 236, Dublin, *ex* Sydney.

Calandra oryzæ, granaria; Tribolium castaneum; Læmophlœus pusillus.

Lariophagus distinguendus Först. also occurred.

Wheat, 247, Cork, *ex* Sydney.

Calandra oryzæ, granaria; Rhizopertha dominica; Silvanus surinamensis.

Cephalonomia sp. also occurred.

Wheat, 262, London, *ex* Sydney.
Calandra oryzæ ; Tribolium confusum ; Læmophlœus pusillus.
Lariophagus sp. (utibilis Tuck.), *distinguendus* Först. and *Cephalonomia sp.* also occurred.

Wheat, 266, London, *ex* Sydney.
Calandra oryzæ ; Rhizopertha dominica ; Tribolium castaneum ; Læmophlœus pusillus ; Anthicus floralis.
Lariophagus distinguendus Först. and *Cephalonomia sp.* also occurred.

Wheat, 268, Liverpool, *ex* Port Adelaide.
Calandra oryzæ, granaria ; Tribolium castaneum.
Lariophagus distinguendus Först., *sp.* (utibilis Tuck.) and *Chætospila elegans* Wstwd. also occurred.

Wheat, 291, Belfast, *ex* Port Pirie (S. Australia).
Calandra oryzæ, granaria ; Tribolium castaneum ; Silvanus surinamensis ; Læmophlœus pusillus.
Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 292, London, *ex* Sydney.
Calandra oryzæ, granaria ; Latheticus oryzæ ; Cathartus advena.
Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 337, London, *ex* Sydney.
Calandra oryzæ ; Tribolium castaneum ; Silvanus surinamensis.
Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 351, Glasgow, *ex* Port Adelaide.
Calandra oryzæ, granaria ; Rhizopertha dominica ; Tribolium castaneum ; Silvanus surinamensis ; Latheticus pusillus ; Anthicus floralis ; Carpophilus dimidiatus.
Lariophagus distinguendus Först. and *Chætospila elegans* Wstwd. also occurred.

Wheat, 358, Liverpool, *ex* Melbourne.
Calandra granaria.

Wheat, 363, London, *ex* Sydney.
Calandra oryzæ, granaria ; Rhizopertha dominica ; Tribolium castaneum ; Silvanus surinamensis ; Læmophlœus pusillus.
Lariophagus distinguendus Först. also occurred.

Wheat, 373, Manchester, *ex* Karachi.
Rhizopertha dominica ; Tribolium castaneum ; Silvanus surinamensis ; Latheticus oryzæ ; Læmophlœus pusillus.
[N.B.—Calandra did not occur in this sample.]

Wheat, 379, Sunderland, *ex* Fremantle.
Calandra oryzæ, granaria ; Tribolium castaneum ; Silvanus surinamensis ; Læmophlœus pusillus ; Carpophilus dimidiatus. [⊕ Sitotroga cerealella.]
Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 381, Sunderland, *ex* Fremantle.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Alphitobius diaperinus; Tenebrioides mauritanicus.

Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 388, Sunderland, *ex* Fremantle.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Tenebrioides mauritanicus.

Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 420, London, *ex* Karachi.

Calandra oryzæ, granaria; Rhizopertha dominica; Trogoderma khapra; Tribolium castaneum; Bruchus analis; Latheticus oryzæ; Læmophlœus ferrugineus.

Rhabdepyris zeæ Turner and Waterston also occurred.

Wheat, 452, Darjiling.

Calandra oryzæ.

Maize, 453, Ibadan, South Nigeria.

Calandra oryzæ, excl. 24.X.1913.

Chætospila elegans Wstwd.

Wheat, 268, Liverpool, *ex* Port Adelaide.

Calandra oryzæ, granaria; Tribolium castaneum.

Lariophagus distinguendus Först., *sp.* (utibilis Tuck.) and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 290, Manchester, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Cathartus advena; Læmophlœus pusillus.

Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 306, London, *ex* Bombay.

Calandra oryzæ, granaria; Rhizopertha dominica; Trogoderma khapra; Tribolium castaneum.

Wheat, 331, London, *ex* Karachi.

Calandra oryzæ, granaria; Rhizopertha dominica; Trogoderma khapra; Tribolium castaneum.

Wheat, 341, Liverpool, *ex* Sydney.

Calandra granaria; Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 342, Liverpool, *ex* Williamstown (Victoria).

Calandra granaria; Silvanus surinamensis.

Lariophagus distinguendus Först. also occurred.

Wheat, 343, London, *ex* Calcutta.

Calandra oryzæ, granaria; Rhizopertha dominica; Trogoderma khapra; Tribolium castaneum; Latheticus oryzæ; Læmophlœus pusillus.

Wheat, 351, Glasgow, *ex* Port Adelaide.
Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Anthicus floralis; Carpophilus dimidiatus.
Lariophagus distinguendus Först. and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 352, London, *ex* Calcutta.
Calandra oryzæ, granaria; Rhizopertha dominica; Trogoderma khapra; Tribolium castaneum; Silvanus surinamensis; Latheticus oryzæ; Læmophlœus pusillus; Tenebrioides mauritanicus.

Wheat, 356, Glasgow, *ex* Sydney.
Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Carpophilus dimidiatus.
Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 359, Leghorn, *ex* Karachi.
Calandra oryzæ; Rhizopertha dominica; Trogoderma khapra.
Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 380, Sunderland, *ex* Fremantle.
Calandra oryzæ; Tribolium castaneum; Læmophlœus pusillus; Carpophilus dimidiatus; Typhæa stercorea; Tenebrioides mauritanicus.
Lariophagus distinguendus Först., *sp.* (utibilis Tuck.) and *Rhabdepyris zeæ* Turn. and Wtrstn. also occurred.

Wheat, 382, London, *ex* Sydney.
Calandra oryzæ, granaria; Silvanus surinamensis; Læmophlœus pusillus; Carpophilus dimidiatus.
Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 385, Glasgow, *ex* Sydney.
Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Carthartus advena; Tenebrioides mauritanicus.
Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 437, London, *ex* Bombay.
Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Palorus ratzeburgi; Tenebrioides mauritanicus.

Wheat, 438, London, *ex* Bombay.
Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Læmophlœus ferrugineus.

Maize, 454, Lake Nyassa (Nyassaland).
Calandra oryzæ, excl. (W. A. Lamborn).

Wheat, 455, Darling Id. (N.S. Wales).
Calandra.

Vespoidea.

Rhabdepyris zeæ, sp. n., Turner and Waterston.

Wheat, 170 (Type ♀), London, *ex* Bombay.
Calandra oryzæ; Tribolium castaneum; Læmophlœus pusillus; Echocerus maxillosus; Tenebrioides mauritanicus.

Wheat, 307, London, *ex* Bombay.
Calandra oryzæ; Rhizopertha dominica; Trogoderma khapra; Tribolium castaneum; Latheticus oryzæ.

Wheat, 380, Sunderland, *ex* Fremantle (W. Australia).
Calandra oryzæ; Tribolium castaneum; Læmophlœus pusillus; Carpophilus dimidiatus; Typhæa stercorea; Tenebroides mauritanicus.
Lariophagus distinguendus Först., *sp.* (utibilis Tuck.) and *Chætospila elegans* Wstwd. also occurred.

Wheat, 420, London, *ex* Karachi.
Calandra oryzæ, granaria; Rhizopertha dominica; Trogoderma khapra; Tribolium castaneum; Læmophlœus ferrugineus; Latheticus oryzæ; Bruchus analis.
Lariophagus distinguendus Först. and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 428, London, *ex* Bombay.
Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Trogoderma khapra; Læmophlœus pusillus; Latheticus oryzæ; Bruchus analis.

Cephalonomia sp.

Wheat, 201, Avonmouth, *ex* Bunbury (W. Australia).
Calandra oryzæ; Læmophlœus ferrugineus.

Wheat, 206, Cardiff, *ex* Williamstown (Melbourne).
Silvanus surinamensis; Læmophlœus ferrugineus.

Wheat, 222, London, *ex* Fremantle and Albany.
Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.
Lariophagus sp. (utibilis Tuck.) also occurred.

Wheat, 247, Cork, *ex* Sydney.
Calandra oryzæ, granaria; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.
Aplastomorpha vandinei Tuck. also occurred.

Wheat, 262, London, *ex* Sydney.
Calandra oryzæ; Tribolium confusum; Læmophlœus pusillus.
Lariophagus distinguendus Först., *sp.* (utibilis Tuck.) and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 266, London, *ex* Sydney.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Læmophlœus pusillus; Anthicus floralis.

Lariophagus distinguendus Först., *sp.* (utibilis Tuck.) and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 324, Plymouth, *ex* Sydney.

Calandra oryzæ, granaria; Silvanus surinamensis; Læmophlœus pusillus; Ptinus tectus.

Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 347, Liverpool, *ex* Fremantle.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 348, Liverpool, *ex* Fremantle.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Læmophlœus pusillus.

Lariophagus distinguendus Först. also occurred.

Wheat, 349, Liverpool, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Carpophilus dimidiatus.

Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 358, Liverpool, *ex* Melbourne.

Calandra granaria.

Aplastomorpha vandinei Tuck. also occurred.

Wheat, 370, Falmouth, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Anthicus elegans; Carthartus advena; Carpophilus dimidiatus.

Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 371, London, *ex* Adelaide.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis.

Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 378, London, *ex* Sydney.

Calandra oryzæ; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 382, London, *ex* Sydney.

Calandra oryzæ, granaria; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Carpophilus dimidiatus.

Lariophagus distinguendus Först., *sp.* (utibilis Tuck.), and *Chætospila elegans* Wstwd. also occurred.

Wheat, 384, Glasgow, *ex* Sydney.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 386, Glasgow, *ex* Geelong (Victoria).

Calandra granaria; Rhizopertha dominica; Silvanus surinamensis; Læmophlœus pusillus.

Lariophagus distinguendus Först. also occurred.

Wheat, 387, Glasgow, *ex* Geelong (Victoria).

Calandra granaria; Tribolium castaneum, confusum; Silvanus surinamensis; Læmophlœus pusillus; Tenebrioides mauritanicus.

Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 388, Sunderland, *ex* Fremantle.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Silvanus surinamensis; Læmophlœus pusillus; Tenebrioides mauritanicus.

Lariophagus distinguendus Först., *sp.* (utibilis Tuck.), and *Aplastomorpha vandinei* Tuck. also occurred.

Wheat, 389, Sunderland, *ex* Fremantle.

Calandra oryzæ; Tribolium castaneum; Læmophlœus pusillus; Tenebrioides mauritanicus.

Lariophagus distinguendus Först. and *sp.* (utibilis Tuck.) also occurred.

Wheat, 390, Manchester, *ex* Sydney.

Calandra oryzæ; Rhizopertha dominica; Tribolium castaneum; Læmophlœus pusillus; Carthartus advena; Tenebrioides mauritanicus.

Lariophagus distinguendus Först. also occurred.

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FINAL REPORT TO THE COUNCIL OF THE ROYAL SOCIETY AND THE MINISTRY OF AGRICULTURE AND FISHERIES, ON THE WORK OF THE GRAIN PESTS (WAR) COMMITTEE.

Drawn up by the Chairman, Prof. W. A. HERDMAN, C.B.E. F.R.S., and approved by the Committee, October 21, 1920.

This Report is divided into the following three sections :—

I.—Introduction and allocation of the work.
II.—Summary of researches and publications.
III.—Recommendations as to future conduct of the work.

I.—INTRODUCTION, AND ALLOCATION OF THE WORK.

The Grain Pests Committee was appointed by the Council of the Royal Society in June, 1916, as the result of correspondence with the Board of Agriculture and Fisheries, in which the Board requested the Royal Society to appoint a Committee to make investigations "in relation to the damage done to grain by insects." In addition to the scientific experts appointed by the Royal Society, the Committee included a representative of the Board of Agriculture (Mr. J. C. F. Fryer), a member appointed by the milling trade (Mr. Oswald E. Robinson), and subsequently Dr. MacFadden from the Local Government Board. Later on representatives of the Liverpool Grain Trade (Mr. Edward Paul) and of the Incorporated National Association of British and Irish Millers (Mr. A. E. Humphries) were added to the Committee, and relations with the trades concerned were established both in London and Liverpool, so that facilities might be obtained at the warehouses and mills, and that samples might be secured for laboratory investigation.

The Council's reference to the Committee was "to consider the relative economic importance of the species and varieties of insects infesting grain, to suggest measures for combating them, and to enquire into the extent of the actual loss from these pests"; and they placed a sum of £200 at the disposal of the Committee for preliminary expenses. Further grants have been added since. No complete investigations had previously been carried out in the British Isles, and it was hoped that sufficient information would be obtained to show definitely what attitude the country should take in future towards the whole question.

The Committee at once got into relation with the appropriate Government Departments or Committees in India and the Overseas Dominions, and steps were taken for the establishment of corresponding committees in Canada, Australia, South Africa, New Zealand and Russia. Sub-Committees were appointed to draft forms of enquiry and to prepare schemes of preliminary work.

It was decided that the observations and experimental work should be divided between London (dealing with the Insecta) and Liverpool (with the Acarida), with an assistant to be provided at each of these centres. The London work was in the first instance carried out at two centres: (1) at the British Museum (Natural History), under the direction of Mr. J. Hartley Durrant; and (2) at the King's College Department of Household and Social Science, under the direction of Prof. Dendy. Since then sections of the London work have been transferred to the Zoological Department of King's College (Prof. Dendy), and the Physiological Department of the Bedford College for Women (Dr. Edkins). Prof. Goodrich at Oxford undertook at a later stage the investigation of the hymenopterous parasites of some grain pests. At Liverpool the work was carried on by Prof. Newstead in the Department of Entomology in the laboratories of Tropical Medicine at the University, and under Prof. Herdman in the Department of Zoology.

The further allocation of the work eventually decided upon was as follows:—

At the British Museum, Mr. Durrant, with some assistance, undertook the investigation of samples, with a view of identifying the pests, in order to compile a complete list (*see* Report No. 9).

At King's College, Prof. Dendy, with the assistance of Mr. Billinghurst, Miss Courtauld, and later on Mr. Elkington, undertook the investigation of the life-histories and bionomics of weevils and other imported insects (*see* Reports Nos. 1, 3, 4, 5, 6 and 7).

At the Bedford College, Dr. Edkins and Miss Tweedy experimented on the life conditions of the flour moth, *Ephestia kühniella*, and the possibility of controlling this pest by fumigation with various gases (*see* Report No. 4).

At the Liverpool laboratories, Prof. Newstead, with the assistance of Miss H. M. Duvall, B.Sc., and later on of Mr. Morris, undertook the investigation of mites as grain and flour pests from all points of view (*see* Reports Nos. 2 and 8).

The work at the King's College Department of Household and Social Science consisted of the statistical investigation of samples, with a view of determining the amount of damage caused by the pests in question, and was supervised by Dr. G. C. Dixon.

By the end of January, 1917, it was decided by the Committee that the statistical enquiry had established the fact that, judging from the samples examined, a very considerable amount of damage to grain was sustained by the action of the pests, and that the Committee was justified in recommending further investigation on faunistic, bionomic, developmental, and experimental lines at the various laboratories concerned.

Verbal interim reports have been received from time to time from Mr. Durrant on his faunistic work, from Prof. Dendy on the life-history and bionomics of weevils, from Dr. Edkins on his experiments with the flour moth, from Prof. Goodrich on the chalcid hymenopterous parasites, and from Prof. Newstead on the investigation of acarids in grain and flour.

As the result of some of these reports and discussions on the Committee, six shorter "Memoranda" and nine longer "Reports" have been prepared on the various investigations, and these have been published and distributed from time to time by the Royal Society.

During the four years since the appointment of the Committee many samples of infested grain and flour have been submitted for examination and report by Government departments and by the grain and milling trades. Flour, for example, examined at the request of the Food Controller, has been found to be infested with the larvæ of *Ephestia*, and samples of flour submitted by the Local Government Board were found to be heavily infested with mites.

In addition to reports on these and other samples, correspondence has been carried on with the Government Departments or Special Committees in Australia, Canada, the United States, Italy, Malta and Cyprus, and answers have been given to enquiries from the Royal Commission on Wheat Supplies, the Imperial Institute, and some members of the trades concerned.

The present Final Report (No. 10 of the series) gives a summary of all the work carried out, and certain recommendations as to such work in the future, approved by the Committee for transmission to the Council of the Royal Society and the Ministry of Agriculture and Fisheries.

II.—SUMMARY OF RESEARCHES AND PUBLICATIONS.

The Committee has issued two series of publications:—(1) Six "Memoranda" which were intended to be temporary and provisional, for the purpose of making known speedily from time to time to the Council of the Royal Society, the Royal Commission on Wheat Supplies, our corresponding committees in the Colonies, and other interested bodies, the progress of the investigations and any conclusions arrived at; and (2) ten "Reports" of a more detailed and permanent nature and which for the most part superseded the "Memoranda."

Memorandum No. 1 (July, 1917) dealt with current views as to the damage done to stored grain and flour by insects and mites, and drew attention to the methods of prevention adopted in the United States and Canada, viz., the application of moderately high temperatures, and in India, where the grain is passed at intervals over a current of air so regulated as to remove the adult weevils and damaged grain. It was pointed out also that low temperatures and dry conditions are unfavourable to grain insects.

Memorandum No. 2 (December, 1917), by Miss H. M. Duvall, was the first of a series of publications by Prof. Newstead and his assistants, dealing with their investigation of the grain mites. These investigations recorded the species of Acarida concerned, the nature of the resulting injury to the grain and flour, the conditions under which the mites live and multiply, the sources of infection and practical methods of prevention. As the later Reports (Nos. 2 and 8) by Prof. Newstead cover the whole field of investigation, no further summary of this Memorandum is necessary.

Memorandum No. 3 (January, 1918) was a report, drawn up by the Chairman, to the Council of the Royal Society, on the progress of the work.

Memorandum No. 4 (December, 1918), the second Memorandum on mites by Prof. Newstead and Miss Duvall, consisted largely of a reprint of the Economic and Experimental section of their Report No. 2, issued in this form for convenience of circulation to millers, at the request of Mr. A. E. Humphries. A large edition, illustrated by plates showing the characteristic appearance of the ravages of acarids in grain and in flour, was printed off and distributed to the trade at the request of the Incorporated National Association of British and Irish Millers.

Memorandum No. 5 (March, 1919) was an interim report to the Council of the Royal Society, drafted by Mr. Fryer at the request of the Committee, for the purpose of making suggestions as to future grain pests investigation in this country. This Memorandum was forwarded by the Council to the several Government Departments concerned.

Memorandum No. 6 (December, 1919), by Mr. H. R. Rathbone of the Royal Commission on Wheat Supplies, was prepared for the special purpose of laying before the Committee the methods and results of the Australian experiments under the following circumstances:—

In the spring of 1917, after consultation with this Committee, the Royal Commission on Wheat Supplies sent an entomologist (Professor Maxwell Lefroy) and a business man (Mr. R. A. Love) to Australia to investigate and report upon the condition of the vast supply of grain accumulated there. On their return the Royal Commission suggested that it might be advisable that the Grain Pests Committee should hear and discuss the Australian results. The Committee appointed a special meeting for the purpose, and as it was found impossible to secure the presence of Prof. Lefroy, through the kind offices of Mr. Hugh Rathbone (a member of the Royal Commission) Mr. Love attended the meeting and laid before the Committee a detailed account of the observations and remedial measures, illustrated by photographs and plans of the machinery adopted for freeing the stored grain from insect pests. The Committee invited Mr. Love to put his remarks in writing for publication, but at Mr. Love's request the account which the Committee issued as their Memorandum No. 6 was written by his colleague, Mr. Hugh Rathbone. In addition to the description of the Australian results, this Memorandum contained some general remarks upon the effect of pests upon grain which, coming from a leading member of the grain trade and a Member of the Royal Commission, were of interest in connection with the work of the Committee. The methods adopted in Australia as a result of the Royal Commission's investigations were, in brief, (1) to temporarily seal up the more heavily infested lots with a covering of malthoid and to pump in carbon dioxide. The wheat was then left until such time as it could be more effectively dealt with by (2) passing it through a heated sterilising chamber at a temperature of 140°–145° F. For further details of the machinery and methods reference must be made to Memorandum No. 6.

Report No. 1 (May, 1918) recorded in detail Prof. Dendy's first series of experiments on the effect of air-tight storage upon grain insects. The object of this and succeeding reports by Prof. Dendy and his assistants was to provide definite experimental evidence with regard to the effect of hermetical sealing upon weevils, so as to test the scientific basis for the native practice in India and other parts of the world of storing grain in underground more or less air-tight pits. Opinions have differed in the past as to whether any ventilation is necessary for the existence of grain pests, and as to whether the immunity of such stored grain from weevils is due to the absence of oxygen necessary for the respiration of the insects or to the lethal effect of the carbon dioxide produced by the respiratory processes both of the weevils and of the grain itself.

The eleven experiments, differing slightly in character, described in this report, all demonstrate the lethal effect of hermetical sealing upon the weevils *Calandra granaria* and *C. oryzæ*, but further experimental work seemed necessary in order to determine what factors were at work in producing the lethal effect. Prof. Dendy claims that within the limits of a wide range of conditions as to temperature, moisture, and degree of weevilling, hermetical sealing is a very effective method of dealing with the weevil problem; and that when once the initial difficulties of construction have been surmounted, the method of air-tight storage seems likely to prove extremely valuable wherever large quantities of grain have to be stored for long periods, especially in warm climates.

Report No. 2 (October, 1918) is mainly occupied with a detailed account by Prof. Newstead and Miss Duvall of the acarids of stored grain and flour. But it also contains two Appendices, one on the bacteriology of some samples of damaged flour by Dr. J. M. Beattie, Professor of Bacteriology in the University of Liverpool, and the other by Mr. Humphries, member of the Royal Commission, recording some experiments on the introduction of mites into flour of known composition. Most of this work on mites was carried out in the University of Liverpool, supplemented by observations at the docks. Liverpool is the chief port of entry for Canadian wheat, and it is also the largest storage and milling port in the United Kingdom. Hence it is possible, in addition to work in the laboratories, to survey the wheat in ship, granary, and mill, and also (what is of special importance in an investigation of this kind) to keep in constant touch with the practice and requirements of the trade.

Four species of Tyroglyphid mites were found in the grain, by far the most important being *Aleurobius farinæ*, which is also the only mite found up to that time in flour. This mite is responsible for most of the damage to both wheat and flour in the Liverpool granaries.

The chief conclusions arrived at in this Report are :—

1. Mites will not injure wheat and flour in which the moisture is 11 per cent. and under, whatever the temperature may be. They may flourish and increase exceedingly when the moisture is over 13 per cent.
2. Given favourable (to them) moisture conditions, increase is very rapid at temperatures between 60° and 75° F., less so between 50° and 60° F., while between 40° and 50° F. increase is slow.
3. The remedy for mite-infested wheat is to screen it thoroughly, in order to remove as many of the mites as possible, and subject it to some treatment whereby the excessive moisture is reduced, such as a blast of hot air followed by cooling.
4. The injury to flour is much more serious and much less readily combated than in wheat. Flour which is heavily mite-infested is unfit for human consumption.

Prof. Beattie examined some samples of badly infested flour and isolated three organisms—a coccus and two bacilli—which seemed to be concerned in causing the damage. The bacterial degeneration of the flour only takes place when a certain amount of moisture is present, and the bacteria are probably introduced by the excreta of the mites.

In Report No. 3 (November, 1918) Prof. Dendy and Mr. Elkington gave the results of their further experiments on the effect of air-tight storage on grain insects. They produced further evidence as to the efficacy of hermetical sealing, and extended their observations to the immature stages of the species of Calandra and also to certain other grain beetles, and the notorious flour moth *Ephestia kühniella*, and they found that all these insects are destroyed by hermetical sealing under the same conditions as the grain weevils. In the same Report Prof. Dendy recorded a series of experiments showing that the two small grain beetles *Tribolium castaneum* and *Silvanus surinamensis*, although frequently found in damaged grain, are unable to attack sound wheat. They are apparently only "secondary" grain pests, feeding upon the debris produced by the attacks of weevils, and incapable themselves of injuring sound grain.

Prof. Dendy also notes in this Report the great attraction which water had in his experiments for certain species of weevils.

In Report No. 4 (April, 1919) Prof. Dendy has two short notes. The first, on the phenomenon known as "webbing" in stored grain, which he showed to be due to the spinning of silk by the larvæ of a very destructive insect, *Ephestia elutella*, and possibly also by other insects.

The second note is on the occurrence of live insects in tins supposed to be hermetically sealed. It was shown that tins, supposed to be "intact," which contained live insects, when tested for leakage by plunging in hot water, showed escape of air-bubbles and were not really air-tight. This note is claimed to prove that the supposed power of some insects to remain alive indefinitely in hermetically sealed tins is a fallacy. It also shows the importance of testing such tins for leakage before they are put in store.

Report No. 4 contained also the result of the work by Dr. Edkins, assisted by Miss Nora Tweedy, on the effects of various gaseous reagents upon the flour moth (*Ephestia kühniella*) and other insect pests found in flour. The gases experimented with included formaldehyde, sulphur dioxide, ammonia, ether, alcohol, extracts of "Keating" and ozone. For various reasons all were found unsatisfactory with the exception of ozone. The experiments with this gas are given in detail, and the following conclusions are drawn :—

Ozone appears to prevent development of *Ephestia* in flour in concentrations of about 50 in a million, if delivered in dry air, for the following reasons :—

1. It tends to destroy the moth, though not to kill the larvæ to any appreciable degree.
2. It appears to inhibit the transformations. Though the animals may not be destroyed they seem to be deprived of their normal powers of continuing development (absence of cocooning and egg-laying).
3. The presence of ozone in the air in a concentration of more than five in a million would be injurious to human life. It could therefore be used in closed circuits in perhaps 50 in a million, but not in the air to be breathed by man.

Report No. 5 (July, 1919) deals with the prevention of heating in wheat by means of air-tight storage, by Prof. Dendy and Mr. H. D. Elkington. The argument used is, that as the "heating" is due to processes of fermentation which depend upon the presence of oxygen, total deprivation of oxygen such as occurs in air-tight storage must result in the prevention of heating. The experiments described in the report demonstrate that "heating" of wheat does not take place in hermetically sealed vessels under the conditions given, and it is fairly safe to argue that it could not take place in large masses of grain in air-tight storage.

Report No. 6 (January, 1920) contains the third and final part of the work by Prof. Dendy and Mr. Elkington on the effect of air-tight storage on grain pests. It consists of a very complete and detailed physiological and chemical investigation of the causes and accompanying conditions of the lethal effect observed. The chief conclusions arrived at are as follows:—

1. Grain insects sealed up in air-tight vessels, with or without wheat, succumb as soon as the oxygen has been used up, a corresponding amount of carbon dioxide being produced.
2. The only gases present in such sealed vessels, under normal conditions, are oxygen, nitrogen, and carbon dioxide.
3. The amount of carbon dioxide given off by live wheat in air-tight, vessels varies directly with the moisture content and the temperature.
4. The complete absence of oxygen is alone sufficient to kill weevils without taking into account the presence of carbon dioxide though they are able to remain alive for a considerable time when only small percentages of oxygen are present.
5. Carbon dioxide exerts a poisonous effect upon weevils apart altogether from the question of diminished oxygen pressure. Thus, at 30°-31° C., *Calandra oryzæ* was killed in less than twelve days in an atmosphere containing from 14·08 to 22·56 per cent. of CO_2, though 13·88 per cent. of O_2 still remained.
6. Pure (moist) carbon dioxide is less fatal in its effects than carbon dioxide with a small admixture of oxygen.
7. Pure (moist) carbon dioxide acts almost instantaneously as a narcotic, under the influence of which weevils may remain motionless for a long time without losing their power of recovery.

The Report terminates with a general discussion on the efficacy and advantage of air-tight storage for cereals, in which it is pointed out that it is highly desirable, as a sequel to the laboratory experiments, that the practicability of the method should be tested on a commercial scale.

The advantages of air-tight storage are summed up as follows:—

1. It sterilises the grain by destroying insects in all stages, or other vermin which may be present.
2. It prevents, absolutely, the access of insects and other vermin.
3. It prevents even grain with a high moisture content from becoming mildewed, as we have shown by experiments not described in these reports.
4. It prevents even grain with a high moisture content from heating (but it does not prevent the development of acidity, due presumably to anærobic fermentation, if the moisture content is excessive).

5. It prevents the absorption of moisture from the atmosphere, so that grain, if stored dry, will remain dry.
6. It saves labour and expense by doing away with the necessity for turning the grain over, or running it from one silo into another, in order to prevent heating.

For further details both as to the conditions and results of the experiments, and also as to the practical applications to the storage of grain in large quantities, reference must be made to the Report (No. 6) itself.

Report No. 7 (January, 1920) contains the last part of the laboratory experimental and bionomic work by Prof. Dendy and Mr. Elkington, and deals with the vitality and rate of multiplication of the grain weevils, Calandra and Rhizopertha, under various conditions of temperature and moisture. In *C. oryzæ* they find an increase of as much as 700-fold in 16 weeks, at an average temperature of 82·5° F., which may be regarded as the optimum temperature for the breeding of both species of grain weevils. In both species also the lower limit for breeding is about 65° F., and multiplication in this country takes place only during the warmer months.

The summary of results from these experiments and observations includes the following:—

1. Under suitable conditions of temperature and moisture, and with an abundant supply of wheat, *Calandra oryzæ* and *C. granaria* show a very high rate of increase and breed all the year round.
2. The optimum temperature for the breeding of *Calandra oryzæ* and *C. granaria* is about 82° F., for *Rhizopertha dominica* somewhat higher.
3. At all temperatures, and under all conditions when breeding takes place at all, *Calandra oryzæ* increases much more rapidly than *C. granaria*, the maximum observed for the former species being a 700-fold increase in 16 weeks, at an average temperature of 82·5 F. For this reason *C. oryzæ* is a more serious danger than *C. granaria*, unless, indeed, in this country, the higher rate of increase is counterbalanced by the higher death-rate of the adults in winter.
4. At ordinary room temperatures in this country both *Calandra oryzæ* and *C. granaria* multiply only during the warmer months of the year, the lower temperature limit for multiplication being probably about 65° F., while for *Rhizopertha* it is probably about 70° F.
5. At ordinary room temperatures nearly all adults of *Calandra oryzæ* are killed off during the winter, but large numbers of larvæ survive in the interior of the grains. The adults of *C. granaria*, on the other hand, survive the winter in large numbers, the death-rate being little, if any, higher than at other times of the year.

6. The adults of the three species show remarkable differences in their susceptibility to cold. After being kept at a temperature of 33–36° F. for 11 days, 91 out of 100 *C. granaria* recovered, only 3 out of 100 *C. oryzæ* showed very feeble signs of life, and none out of 100 *Rhizopertha dominica* recovered.

7. *Rhizopertha dominica* is less susceptible to high temperatures than the two weevils, the lethal temperature for an exposure of three minutes being about 146° F. for the former and between 120° and 131° F. for the latter (in the adult condition).

8. An exposure to a temperature of 145·5° F. for five minutes is sufficient to kill the larvæ of *C. oryzæ* and probably to sterilise the wheat completely as regards all insect life.

9. Although a moist atmosphere is undoubtedly more favourable than a dry one for the two weevils, both species can live and multiply in a dry incubator, *C. oryzæ* increasing much more rapidly than *C. granaria*, provided the initial moisture content of the grain is sufficiently high.

10. Very dry wheat is less liable to attack by weevils than wheat with a moderate or high moisture content, but wheat readily absorbs moisture in a damp atmosphere, and thereby becomes much more susceptible to weevilling.

11. *Rhizopertha* can withstand dry conditions better than either of the two weevils.

12. *Calandra oryzæ* and *C. granaria* are both likely to be serious pests in this country, but little is to be feared from *Rhizopertha dominica* under ordinary temperature conditions.

13. In addition to the damage done by actual consumption of the grain, the presence of weevils results in extensive fouling with fæcal matter, encouraging the absorption of moisture and the ultimate rotting of the whole mass. In large quantities of wheat the process of decay is doubtless accelerated by rise of temperature due partly to the presence of insects and partly to "heating" of the wheat.

Report No. 8 (October, 1920) gives the continuation of Prof. Newstead's work, assisted by Mr. H. M. Morris, in which he discusses the mites found in stored grain and flour at Liverpool under the heads (1) Morphology and Bionomics and (2) Economic and Experimental. He finds that in addition to *Aleurobius farinæ* discussed in his first report, two other mites, *Tyroglyphus longior* and *Histiogaster entomophagus*, are of primary importance, as they are capable of causing considerable damage to stored flour. The other chief conclusions arrived at are as follows:—

1. A relatively high moisture content in both wheat and flour is essential for the existence of the various species of acari.

2. Preventive measures are far more satisfactory than remedial measures.

3. Attacks by mites may be prevented by storing only flour the moisture content of which is below 11 per cent. in the temperate zone, and a much lower percentage in tropical countries.
4. The storing of uninfested flour in hermetically sealed receptacles would no doubt be efficacious if properly carried out; but our experiments show that if the flour is already infested with mites some may survive even after hermetic sealing for over two months.

Prof. Newstead also gives a report on the non-parasitic or forage acari of the family Tyroglyphidæ. These have sometimes been found on the British Army horses in France and sent to us for identification. They are no doubt accidental migrants from the fodder or oats and in no sense parasites, but their resemblance to the closely allied Sarcoptids, which cause acariasis or mange, has in some cases led to the needless isolation of numbers of horses. The Liverpool veterinary surgeon, Captain Noel Pillers, who had much experience of such mites on horses in France during the war, has contributed some clinical notes to Prof. Newstead's report.

In Report No. 9, Mr. Durrant gives a complete list of all the grain pests identified during the work of the Committee, with information as to their relative abundance and importance as pests, along with their geographical distribution, and a description of those hymenopterous parasites of the grain pests which proved to be new to science or unrecognised.

In this Report (No. 9) also, Prof. Goodrich has an article giving the result of his researches on the hymenopterous parasites of grain pests. The report shows that the commonest species are *Chætopsila elegans* and *Lariophagus calandræ* belonging to the family Chalcididæ; that they attack and kill the larvæ of *Rhizopertha dominica*, *Calandra oryzæ*, and *C. granaria*; and that since the chalcids often occur in large numbers, and the beetles named above are the most destructive insects found in grain, the parasites are valuable allies in the fight against grain pests. But although they act as a check on the multiplication of the beetles they do not exterminate them. Both weevils and hymenopterous parasites survive for an indefinitely long time in infested wheat. The report shows that this is due to a balance being established, owing to the parasites themselves falling a prey to a carnivorous acarid.

Report No. 10 is the present "Final Report" drawn up by the Chairman at the request of the Committee.

III.—RECOMMENDATIONS AS TO FUTURE WORK.

In March, 1919, the Committee realised that their investigations, as a matter of urgency and under war conditions, were drawing to a conclusion, but that they had revealed the real value of such work, and that sufficient information had already been obtained to show that the whole subject of grain pests is of serious importance to the Empire, and that a permanent organisation should be brought into being to deal, not merely with insect pests, but with all living organisms causing destruction to vegetable food-stuffs. Under these circumstances they considered that definite proposals for the future conduct of the work should be made without delay. The Committee therefore drew up and submitted to the Council of the Royal Society a report (Memorandum No. 5) dealing with the future organisation of Grain Pests work in the British Isles and containing the following recommendations:—

(A.) RESPONSIBILITY FOR THE WORK.

In the first place, it is the opinion of the Committee that the State should assume a general responsibility for the continuance of grain pests work. This, however, does not imply that the State should carry out the entire work through the agency of Government officials. The range of work needed can be classified under four distinct heads; and before attempting to formulate any definite scheme, it may be well to suggest that certain sections should be directly undertaken by a Government Department, while others should be delegated to bodies or individuals not under State control.

(i.) *Intelligence.*

This work requires free access to ships, docks, granaries, and mills, facilities for travel, and also the authority which the status of a Government official carries. There are other reasons, but those just mentioned seem alone sufficient for centreing this section of the work in a Government Department. (Such a Department would, however, need to make the fullest use of unofficial reporters if its records were to be at all complete.)

(ii.) *Research.*

The view is somewhat generally expressed that a Government Department should not undertake research, but this is probably due to the fact that the term "research" is considered as including only its more "academic" or "detached" aspects. The work is used here as covering every form of investigation which may be needed in order to place the control of a pest on a purely commercial basis. Under such an interpretation there appear to be certain aspects which a Government Department is best equipped to carry out, while there are others which, perhaps, are at least as well, possibly better, done elsewhere. To take an instance, a lengthy piece of work on the physiology of respiration in insects could probably best be carried out in a University laboratory. On the other hand, suppose this research provided a valuable clue to the control of a pest in practice, little good (so far as the trade and the public are concerned) would result until this clue had been followed up to the stage when commercial results were obtained. This implies the carrying out of large-scale experiments, often of a most expensive character, under the actual conditions of trade. Such work can only be done either by a Government Department or by the trade itself; but there are many disadvantages in the latter alternative, and the former appears much to be preferred. It is therefore suggested that a Government Department should be in charge of the last stages—the more practical or administrative stages of research—leaving the earlier stages to the University or independent worker. It is obvious that even in the later stages there must be some mechanism for co-operation between the laboratory researchers and the Government officials concerned.

(iii.) *Education.*

There are two main sections in this division of the work. In the first place, an advisor or consulting expert is required, who will advise the trade in individual cases. Secondly, the results of research should be brought prominently to the notice of the public concerned. In the former, the advisor must be sufficiently free from other duties to give prompt advice, and also he must be able to visit cases in person. In the latter, in addition to propaganda work by leaflets, &c., there should be some arrangement for carrying out large scale demonstration experiments which are far more effective in educating a skilled profession in new methods. On the whole, the most economical way of dealing with education would seem to be through a Government Department, an alternative method being by means of some arrangement with Universities and Institutes in the chief grain centres. In the latter event, however, it would be essential that each institution should be properly equipped, and have on its staff a man really qualified to advise.

(iv.) *Administration.*

This subject requires no discussion, as it is clearly a question for the Government.

(B.) SUGGESTED SCHEME.

In the previous section, conclusions have been reached as to the nature and classification of work against grain pests, and also the position towards it which the State should be recommended to adopt. If the work is to be placed on a permanent basis, it should be made clear from the beginning that it must be carried through to its logical conclusion, the practical control of grain pests; and provision for work in each division should ultimately be made. At the same time this does not imply that the Government should be recommended to set up at once a large organisation—in fact, from all points of view, it seems preferable to suggest the formation of a nucleus organisation which would be capable of expansion as the importance of its work became apparent. Such a nucleus might be somewhat as follows:—

(*a*) The Government Department charged with grain importation and storage should appoint two or three officials with a fairly wide scientific training, combined, in at least one case, with a special knowledge of Entomology, and in another, of practical grain storage and milling. At first, at all events, the duties of these men would be primarily of the intelligence order.

(*b*) The Department should also institute a small Committee, consisting of trade, scientific and official members (including one representative each of the Ministry of Food, Board of Trade, Colonial Office, Ministry of Agriculture and Fisheries). It should be the duty of the Committee to organise research, to ensure the application of scientific results to practical processes, and to see that practical methods are based upon a genuine scientific foundation.

(*c*) The Department for Scientific and Industrial Research should make to the Committee an annual grant of money to be administered by the Committee for the purposes of research. This sum would be independent of that necessary to provide salaries and working expenses for the Department's own official workers.

(*d*) Without offering a very definite opinion on the matter, it might prove advisable to select certain University laboratories as being specially suitable for grain pest work. Grants in aid would then be conditional on the work being carried out in these laboratories, and a tradition in favour of grain pest work might be developed which would tend to bring about continuity and economies in apparatus.

(*e*) The question of financing the scheme in part on a contributory basis might be considered, but it is believed that before such support from the trade could be obtained, it would be necessary to produce clear evidence of work useful from a commercial point of view.

The above recommendations give a brief indication of a possible nucleus organisation to deal with grain pest work. Nothing has been said as to which Department should be responsible for the work, beyond the fact that it should be the same Department as is in charge of grain import and storage, presumably the Board of Trade. In some aspects, however, the proposed work is closely related to that of the Ministry of Agriculture. Another Department also—the Colonial Office—is closely concerned with the subject, and already has its own entomological section—the Imperial Bureau of Entomology. From all points of view the co-operation of the Bureau would be desirable, notably in connection with the intelligence work, and it should at least be represented on the Committee indicated under (*b*) above. The Department for Scientific and Industrial Research might be willing to take up the scheme on the lines suggested above.